DECLARATION

I, Toshio TAKAMATSU, a citizen of Japan, c/o Miyoshi & Miyoshi of Toranomon Daiichi Bldg., 2-3, Toranomon 1-chome, Minato-ku, Tokyo 105-0001, Japan, do hereby solemnly and sincerely declare:

That I am well acquainted with the Japanese language and English language; and

That the attached is a true and faithful translation made by me of the Japanese document, namely Japanese Patent Application No. 2001-381889 to the best of my knowledge and belief.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-captioned application or any patent issuing therefrom.

This 11th day of August, 2003

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JAPAN PATENT OFFICE

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Date of Application:	December 14, 2001
Application Number:	Patent Application No. 2001-381889
[ST.10/C]:	[JP2001-381889]
Applicant(s):	NISSAN MOTOR CO., LTD.

January 18, 2002

Commissioner, Japan Patent Office — Kozo Oikawa

Number of Certification: 2001-3116773

【Kind of Document】	Patent Application
【Case No.】	NM01-01441
【Filing Date】	December, 2001
【Address】	Commissioner Patent Office, Kozo OYOBIKAWA
【International Cl.】	G01N 21/88
【Title of the Invention】	LASER WELD QUALITY MONITORING METHOD AND SYSTEM
【The Number of Claims】	24
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【Claim for Priority based on the Prior Application】
【Application No.】 Japanese Patent Laid-Open No. 2001-48756
【Filing Date】 February 23, 2001
【Identification of Charge】
【No. of Payment】 001719
【Amount】 ¥21,000
【List of Filed Documents】
【Document】 Specification 1
【Document】 Drawing 1
【Document】 Abstract 1
【Blanket Letter of Attorney No.】 9810193

[Name of Document] SPECIFICATION

[Title of the Invention] LASER WELD QUALITY MONITORING METHOD AND SYSTEM

[Claim for a Patent]

[Claim 1] A laser weld quality monitoring method, comprising the steps of:

irradiating laser beams from a YAG laser toward a welding part of a workpiece;

detecting reflected lights from the welding part of the irradiated laser beams;

calculating a frequency distribution of a signal obtained from the detected reflected lights;

calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and

if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[Claim 2] A laser weld quality monitoring method according to claim 1, comprising the steps of:

calculating the frequency distribution;

converting the detected reflected light to an electric signal; and

calculating the frequency distribution of the electric signal based on a variation per hour of the converted electric signal.

[Claim 3] A laser weld quality monitoring method according to claim 1 or 2, wherein a specified frequency band for calculating the signal intensity is varied in accordance with at least one numeric value out of a plate thickness of the

workpiece, a welding speed and an aspect ratio H/D calculated from a depth H of a keyhole of a welding part in the workpiece and a width D of the keyhole.

[Claim 4] A laser weld quality monitoring method according to claim 1 or 2, wherein the calculation of the signal intensity is carried out by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[Claim 5] A laser weld quality monitoring system, comprising:

a YAG laser for irradiating laser beams toward a welding part of a workpiece;

a reflected light detecting means for detecting reflected lights from the welding part of the irradiated laser beams;

an electric signal converting means for converting the detected reflected light to an electric signal;

a frequency distribution calculating means for calculating a frequency distribution of the electric signal based on a variation per hour of the converted electric signal;

a signal intensity calculating means for calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and

a weld quality determining means for, if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

[Claim 6] A laser weld quality monitoring system according to claim 5, wherein the reflected light detecting means has an interference filter for passing only lights of a wavelength of the YAG laser beams in order to detect only the reflected lights of the YAG laser beams.

[Claim 7] A laser weld quality monitoring system according to claim 5, wherein the signal intensity calculating means varies a specified frequency band for calculating a signal intensity in accordance with at least one numeric value out of a plate thickness of the workpiece, a welding speed and an aspect ratio H/D calculated from a depth H of a keyhole of a welding part in the workpiece and a width D of the keyhole.

[Claim 8] A laser weld quality monitoring system according to claim 5, wherein the signal intensity calculating means calculates a signal intensity by using a fast Fourier transform (FFT) for calculating a frequency distribution of the signal intensity or a band filter for passing a signal of only the specified frequency band.

[Claim 9] A laser weld quality monitoring method, comprising the steps of:

irradiating laser beams from a YAG laser toward a welding part of a workpiece;

detecting reflected lights from the welding part of the irradiated laser beams;

calculating a frequency distribution of a signal obtained from the detected reflected lights;

calculating at least one signal intensity of a signal intensity in a first frequency band for detecting an occurrence of an under-filled state and a signal intensity in a second frequency band for detecting an occurrence of porosity, and a signal intensity in a third frequency band for detecting an occurrence of a non-welded state, among the detected frequency distribution;

virtually plotting the signal intensity of each of the calculated frequency bands by using a virtual biaxial coordinate system that one axis denotes a magnitude of the signal intensity of the first frequency band and the second frequency band and another axis denotes a magnitude of the

signal intensity of the third frequency band; and

determining an occurrence of at least one welding state out of the under-filled state, the porosity and the non-welded state according to an area where the signal intensity of each of the frequency bands is plotted in the biaxial coordinate system.

[Claim 10] A laser weld quality monitoring method according to claim 9, comprising the steps of:

calculating the frequency distribution;

converting the detected reflected light to an electric signal;

storing a variation per hour of the converted electric signal;

calculating the frequency distribution of the electric signal based on the variation per hour of the electric signal.

[Claim 11] A laser weld quality monitoring method according to claim 9 or 10, wherein an under-filled area, a porocity area and a non-welded area are prescribed in the biaxial coordinate system for determining an occurrence of any welding state of the under-filled state, the porocity and the non-welded state.

[Claim 12] A laser weld quality monitoring method according to claim 11, wherein a non-defective area is prescribed in the biaxial coordinate system for determining that no welding state of the under-filled state, the porocity and the non-welded state occurs.

[Claim 13] A laser weld quality monitoring method according to claim 12, wherein a mixing area which is difficult to specify a type of welding state is prescribed in each boundary of the under-filled area, the porocity area, the non-welded area and the non-defective area in the biaxial coordinate system.

[Claim 14] A laser weld quality monitoring method according

to claim 13, further comprising the steps of:

when the signal intensity of any frequency band is virtually plotted in the mixing area, dividing a variation per hour of an electric signal stored for one welding part into a plurality of areas on the time-series basis;

calculating a frequency distribution of the electric signal in each area based on a variation per hour of the electric signal in each of the divided areas;

calculating at least one signal intensity of a signal intensity in the first frequency band and a signal intensity in the second frequency band, and a signal intensity in the third frequency band with respect to each frequency distribution calculated in each area;

virtually plotting the signal intensity of each of the calculated frequency bands in each area in the biaxial coordinate system;

determining in each area an occurrence of at least one welding state out of the under-filled state, the porosity and the non-welded state according to an area where the signal intensity of each of the frequency bands is plotted in the biaxial coordinate system; and

determining synthetically a state of quality of the welding part based on the determination.

[Claim 15] A laser weld quality monitoring method according to claim 14, wherein in the step of determining synthetically a state of quality of the welding part, if the number of areas where it is determined that at least one welding state out of the under-filled state, the porosity and the non-welded state occurs exceeds a fixed ratio with respect to the number of the divided areas, it is determined that the quality of the welding part is problematic, and if not, it is not determined that the quality of the welding part is problematic.

[Claim 16] A laser weld quality monitoring method according to any one of claims 9, 10 and 14, wherein each of the first

to third frequency bands for calculating the signal intensity is varied in accordance with at least one numeric value out of a plate thickness of the workpiece, a welding speed and an aspect ratio H/D calculated from a depth H of a keyhole of a welding part in the workpiece and a width D of the keyhole.

[Claim 17] A laser weld quality monitoring system, comprising:

a YAG laser for irradiating laser beams toward a welding part of a workpiece;

a reflected light detecting means for detecting reflected lights from the welding part of the irradiated laser beams;

an electric signal converting means for converting the detected reflected lights into an electric signal;

a storing means for storing a variation per hour of the converted electric signal;

a frequency distribution calculating means for calculating a frequency distribution of the electric signal based on a variation per hour of the electric signal;

a signal intensity calculating means for calculating at least one signal intensity of a signal intensity in a first frequency band for detecting an occurrence of an under-filled state and a signal intensity in a second frequency band for detecting an occurrence of porosity, and a signal intensity in a third frequency band for detecting an occurrence of a non-welded state, among the calculated frequency distribution; and

a weld quality determining means for virtually plotting the signal intensity of each of the calculated frequency bands by using a virtual biaxial coordinate system that one axis denotes a magnitude of the signal intensity of the first frequency band and the second frequency band and another axis denotes a magnitude of the signal intensity of the third frequency band; and for determining an occurrence of at least one welding state out of the under-filled state, the porosity

and the non-welded state according to an area where the signal intensity of each of the frequency bands is plotted in the biaxial coordinate system.

[Claim 18] A laser weld quality monitoring system according to claim 17, the reflected light detecting means comprises an interference filter for transmitting only lights of a wavelength of the YAG laser beams in order to detect only reflected lights of the YAG laser beams.

[Claim 19] A laser weld quality monitoring system according to claim 17, wherein an under-filled area, a porocity area and a non-welded area are prescribed in the biaxial coordinate system for determining an occurrence of any welding state of the under-filled state, the porocity and the non-welded state.

[Claim 20] A laser weld quality monitoring system according to claim 19, wherein a non-defective area is prescribed in the biaxial coordinate system for determining that no welding state of the under-filled state, the porocity and the non-welded state occurs.

[Claim 21] A laser weld quality monitoring system according to claim 20, wherein a mixing area which is difficult to specify a type of welding state is prescribed in each boundary of the under-filled area, the porocity area, the non-welded area and the non-defective area in the biaxial coordinate system.

[Claim 22] A laser weld quality monitoring system according to claim 21, further comprising:

a dividing means for, when the signal intensity of any frequency band is virtually plotted in the mixing area, dividing a variation per hour of an electric signal stored in the storing means with respect to one welding part into a plurality of areas on the time-series basis, wherein

the weld quality determining means determines an

occurrence of at least one welding state out of an under-filled state, a porosity state and a non-welded state in each area, and determines synthetically a state of quality of the welding part based on the above determination.

[Claim 23] A laser weld quality monitoring system according to claim 22, wherein if the number of areas where it is determined that at least one welding state out of the under-filled state, the porosity and the non-welded state occurs exceeds a fixed ratio with respect to the number of the divided areas, the weld quality determining means determines that the quality of the welding part is problematic, and if not, the weld quality determining means determines that the quality of the welding part is problematic.

[Claim 24] A laser weld quality monitoring system according to claim 17 or 22, wherein each of the first to third frequency bands for calculating the signal intensity is varied in accordance with at least one numeric value out of a plate thickness of the workpiece, a welding speed and an aspect ratio H/D calculated from a depth H of a keyhole of a welding part in the workpiece and a width D of the keyhole.

[Detailed Description of the Invention]

[Field of the Invention]

The present invention relates to a laser weld quality monitoring method and system. In particular, the invention relates to a laser weld quality monitoring method and system adapted to monitor an occurrence of a welding state such as a porocity, an under-filled state and an unwelded state in a laser welding part.

[Prior Art]

The welding of very thin steel sheets, such as for a vehicle body, is performed by a laser welding. In comparison with a spot welding, the laser welding has many advantages such that it is applicable to a one-side welding without the need of clamping steel sheets from both obverse and reverse, and that it allows an easy welding even at an inside of a fine complicate groove. However, as a disadvantage, it tends to suffer a degradation of welding quality caused by a failed lapping accuracy between steel sheets or accrued suddenly at a stained welding part.

Therefore, hitherto, the monitoring method of a laser welding part is performed by predicting a laser weld quality in a real-time manner. Japanese Patent Application Laying-Open Publication No. 2000-271768 has disclosed techniques of using two sensors having their detection angles different from each other, for sensing lights from a plume occurring at a keyhole in the laser welding part and reflected lights of a YAG (Yttrium Aluminum Garnet) laser radiated, to detect variations of output, focal position, and inter-sheet gap as welding conditions by intensities of light detected by each sensor, thereby performing a real-time prediction of a quality of the laser welding part.

[Problems to be Solved by the Invention]

However, in a conventional weld quality monitoring method, it is possible to detect an occurrence of a welding state (an under-filled state) that a laser welding part is grooved, and an occurrence of a defective welding condition which is deviated from a prescribed welding condition, but there arises a problem that it is difficult to detect an occurrence of porosity (a porous state) of the welding part, occurred during laser welding in a zinc-plated steel sheet, or the like.

The difficulty in detection of an occurrence of porosity in the conventional weld quality monitoring method resides in that a decision on weld quality is made of a state of weld based

on light emitted from a region (keyhole) irradiated and melted by a laser beam. The reason is that the porous state is caused by a mixing of zinc vapor inside the keyhole, which mixing of zinc vapor seldom imparts variations in the light emitted from the keyhole.

Further, in the conventional weld quality monitoring method, in case of a lap welding, if a gap between vertical sheets is too large, a non-welded state that a welding of the vertical sheets is imperfect occurs and there arises the problem that it is difficult to detect an occurrence of this non-welded state.

In the conventional weld quality monitoring method, it is possible to detect an occurrence of a defective welding state and a defective welding condition of the under-filled state except for the porocity and the non-welded state, but the detection method differs according to each type of welding states. Therefore, a very complicated calculation process is necessary for the detection. Accordingly, there arises the problem that a process load of a CPU for the computation process is increased.

Further, in the conventional weld quality monitoring method, when the defective welding state and the defective welding condition of the under-filled state except for the porocity and the non-welded state occurred ranging over the entire welded part, it is possible to readily detect an occurrence of these states. However, when these states occurred in only a part of the welded part, there arises the problem that it is not possible to readily detect an occurrence of these states.

The present invention has been invented with such conventional problems in mind, and it is an object of the present invention to provide a laser weld quality monitoring method and system which can reliably detect an occurrence of a welding state of porosity, an under-filled state and a non-welded state of a laser welding part without enlarging a process load of a CPU, and further can reliably detect an occurrence of the

welding state of the porosity, the under-filled state and the non-welded state of a part of the laser welding part.

[Means for Solving the Problems]

In order to solve the above-described problems and attain the object, the laser weld quality monitoring method comprises the steps of: irradiating laser beams from a YAG laser toward a welding part of a workpiece; detecting reflected lights from the welding part of the irradiated laser beams; calculating a frequency distribution of a signal obtained from the detected reflected lights; calculating a signal intensity in a specified frequency band among the calculated frequency distribution; and if the calculated signal intensity exceeds a preset reference value, determining that an occurrence of porosity is excessive, and if not exceeding the reference value, determining that an occurrence of porosity is within a normal range.

According to a first feature of the present invention, as reflected lights of YAG laser beams suited to detect an occurrence of porocity are detected and only signal intensities of the specified frequency band which are necessary for detecting an occurrence of excessive porosity are extracted from the signals produced based on reflected lights, it is possible to easily determine based on the signal intensity of the extracted signals to what extent porocity occurred. Accordingly, it is possible to reliably detect an occurrence of excessive porocity that was difficult to detect conventionally.

In order to solve the above-described problems and attain the object, according to a ninth feature of the present invention, the laser weld quality monitoring method comprises the steps of: irradiating laser beams from a YAG laser toward a welding part of a workpiece; detecting reflected lights from the welding part of the irradiated laser beams; calculating a frequency distribution of a signal obtained from the detected reflected lights; calculating at least one signal intensity of

a signal intensity in a first frequency band for detecting an occurrence of an under-filled state and a signal intensity in a second frequency band for detecting an occurrence of porosity, and a signal intensity in a third frequency band for detecting an occurrence of a non-welded state, among the detected frequency distribution; virtually plotting the signal intensity of each of the calculated frequency bands by using a virtual biaxial coordinate system that one axis denotes a magnitude of the signal intensity of the first frequency band and the second frequency band and another axis denotes a magnitude of the signal intensity of the third frequency band; and determining an occurrence of at least one welding state out of the under-filled state, the porosity and the non-welded state according to an area where the signal intensity of each of the frequency bands is plotted in the biaxial coordinate system.

According to the ninth feature of the present invention, reflected lights of the YAG laser beams are detected, and the signal intensities of the first to third frequency bands which are suited to detect an occurrence of at least one welding state out of the under-filled state, the porocity and the non-welded state are extracted from signals produced based on the reflected lights, respectively. As determining an occurrence of a welding state of the under-filled state, the porocity and the non-welded state according to an area where the signal intensities are plotted in the biaxial coordinate system, it is possible to reliably detect an occurrence of a plurality of welding states.

[Effect of the Invention]

As described above, according to the first to eighth features of the present invention, as reflected lights of the YAG laser beams suited to detect an occurrence of the porocity are detected and only signal intensities of the specified frequency band which are necessary for detecting an occurrence of excessive porosity are extracted from the signals produced

based on the reflected lights, it is possible to reliably detect an occurrence of excessive porocity that was difficult to detect conventionally.

Further, the specified frequency band for calculating the signal intensity is varied in accordance with at least one numeric value out of a plate thickness of the workpiece, a welding speed and an aspect ratio H/D calculated from a depth H of a keyhole of a welding part in the workpiece and a width D of the keyhole. Therefore, it is possible to dissolve variations of occurrence detection accuracy of the porocity caused by a difference in the plate thickness, the welding speed and the aspect ratio.

Further, according to the ninth to twenty-fourth features of the present invention, reflected lights of the YAG laser beams are detected, and the signal intensities of the first to third frequency bands which are suited to detect an occurrence of at least one welding state out of the under-filled state, the porocity and the non-welded state are extracted from signals produced based on the reflected lights, respectively. As determining an occurrence of a welding state of the under-filled state, the porocity and the non-welded state according to an area where the signal intensities are plotted in the biaxial coordinate system, it is possible to reliably detect an occurrence of a plurality of welding states. Further, when the occurrence of any welding state or the non-occurrence of any welding state cannot be determined definitely, a variation per hour of an electric signal stored for one welding part is divided into a plurality of areas on a time-series basis, and a state of quality of the welding part is determined again as to each divided area. Therefore, it is easy to determine synthetically presence or absence of an occurrence of any welding state, and further it is possible to determine an occurrence of any welding state with high accuracy.

[Preferred Embodiment]

Hereinafter, a laser weld quality monitoring method and system according to a preferred embodiment of the present invention will be in detail described with reference to the accompanying drawings, by classifying into a first embodiment (corresponding to claims 1 to 8) and a second embodiment (corresponding to claims 9 to 24) and exemplifying a case where a welding member is a zinc-plated steel sheet.

(First Embodiment)

Fig. 1 is an embodied structural diagram of a YAG laser welder equipped with a quality monitoring system according to the present invention.

An optical fiber cable 2 is attached to an upper part of a YAG laser welder 100, and laser beams from a YAG laser oscillator (YAG laser) (not shown) are led to the YAG laser welder 100 by the optical fiber cable 2. A light converging optical system for converging the led laser beams is disposed ranging from a center part to a lower part of the YAG laser welder 100. The light converging optical system has a collimator lens 3 and a light converging lens 4, and after the led laser beams are changed to parallel lights by the collimator lens 3, the led laser beams are converged on a surface of a workpiece (vehicle body panel) 5 by the light converging lens 4. The light converged part (welding part) is melted by energy of laser beams, so that the workpieces are welded to each other.

Further, in a lower surface of the YAG laser welder 100, a sensor 6a which functions as a reflected light detecting means is disposed at a location of an angle of elevation 60 degrees ($\theta 1$) from a surface of the workpiece 5 and a sensor 6b is disposed at a location of an angle of elevation 10 degrees ($\theta 2$) from a surface of the workpiece 5. The sensor 6a is a sensor for detecting reflected lights of laser beams reflected without being absorbed by the workpiece 5 after irradiated mainly by the welding part. The sensor 6b is a sensor for detecting plasmatic lights (visible lights) produced from the welding

part during welding. A weld quality of the welding part is determined in real time based on lights (reflected lights and plasmatic lights) detected by both the sensors 6a and 6b. As the monitoring method and the monitoring system according to the present invention detect an occurrence of porosity by use of reflected lights of laser beams, the sensor 6a is a particularly important sensor.

Fig. 2 is a conceptual diagram of the YAG laser welder equipped with the quality monitoring system according to the present invention. The YAG laser welder shown in Fig. 2 comprises a YAG laser oscillator 1, and laser beams produced by the YAG laser oscillator 1 are led to a light converging optical system by the optical fiber cable 2, and are changed to parallel lights by the collimator lens 3. Thereafter, lights are converged on a surface of the workpiece 5 by the light converging lens 4, to weld the workpiece 5 by power of the converged laser beams.

On the other hand, the sensor 6a is disposed at a first location where the angle of elevation θ1 is 60° from the surface of the workpiece 5, and reflected lights of a YAG laser reflected without being absorbed by the workpiece 5 after irradiated on a welding part F are converted into an electric signal in accordance with an intensity thereof by the sensor 6a. Accordingly, the sensor 6a functions as an electric signal converting means. Further, the sensor 6b is disposed at a second location where the angle of elevation θ2 is 10° from the surface of the workpiece 5, and plasmatic lights (visible lights) from a plume (metallic vapor at high temperatures) produced in the welding part F during welding are converted into an electric signal in accordance with an intensity thereof by the sensor 6b. The electric signal converted by both the sensors 6a and 6b are input to a measuring device 7 constituted by an amplifier (preamp), a band-pass filter, an A/D converter, a personal computer, or the like.

As shown in Fig. 3, the sensors 6a and 6b comprise two photodiodes 8 and 9, a dichroic mirror 10, and an interference

filter 11 which transmits only a wavelength of 1064 nm ± 10 nm.

In the sensors 6a and 6b, first, lights from the welding part entered from a left side of Fig. 3 are selected in accordance with a wavelength by the dichroic mirror 10. Namely, a visible light of wavelength 500 nm or less is reflected by the dichroic mirror 10 and led to the photodiode 8, and the visible light is converted into an electric signal as a plasmatic light, to detect an intensity thereof. On the other hand, after an infrared light out of an incident light from the welding part transmits the dichroic mirror 10, only a YAG laser beam having wavelength 1.06μm transmits the interference filter 11. The YAG laser beams are led by the photodiode 9, and converted into an electric signal as YAG reflected lights, and input into the measuring device 7, respectively. As the monitoring device and the monitoring system according to the present invention detect an occurrence of porocity by use of reflected lights of laser beams, the electric signal from the photodiode 9 provided in the sensor 6a is used.

Fig. 4 is a diagram showing an embodied constitution of the measuring device 7 shown in Fig. 2. The measuring device 7 is provided corresponding to each of the photodiodes 8 and 9 provided in each of the sensors 6a and 6b. Accordingly, the monitoring device of the present invention is provided with the four measuring devices 7. A constitution of each measuring device 7 is identical.

The measuring device 7 comprises an amplifier (preamp) 7A for amplifying an electric signal from the photodiode 9 to a constant level; A/D converters 7B and 7D for converting an analog electric signal output from the amplifier 7A into a digital electric signal; a band-pass filter 7C for passing only the electric signal of a specified frequency band; a personal computer 7E which functions as a frequency distribution calculating means for calculating a frequency distribution of the input electric signal, functions as a signal intensity calculating means for calculating a signal intensity in the specified frequency band, and functions as a weld quality

determining means for determining a condition of an occurrence of porocity; and a display 7F for displaying a result obtained by determining a weld quality.

Figs. 5 to 7 are views for explaining a principle of detecting a weld quality. The reason that the weld quality can be detected by analyzing lights from the welding part will be described with reference to Figs. 5 to 7. Figs. 5 and 6 show a condition of an occurrence of porocity when a zinc-plated steel sheet as an object to be welded is lap-welded. As shown in Fig. 5, when the YAG laser welder 100 irradiates YAG laser beams of high power density on a butt part 20 of the zinc-plated steel sheet, the irradiated part (welding part) starts melting by receiving energy of laser beams, to form a keyhole 25 in which a metal is melted. At this time, a zinc-plated layer 21 plated on a surface of a steel sheet is varied to a metallic vapor at a melting temperature of a steel 22 as a base metal. Bubble-like porocity (blowhole) 23 occurs in the keyhole 25 by pressure of the metallic vapor.

As shown in Fig. 6, laser beams are absorbed by a wall 26 on a front surface of the keyhole 25. In lap-welding of the zinc-plate steel sheet, when the zinc-plated layer 21 exists on an interface of two steel sheets, a zinc metallic vapor 27 jets into the keyhole 25. This becomes the porocity 23. In welding with the YAG laser beams, as a wavelength of laser beams is short at 1.06μm or thereabout, laser beams are almost transparent with respect to a plume 28 jetted from an opening part of the keyhole 25. Accordingly, the high-speed phenomenon as to presence or absence of the porocity 23 cannot be caught by observation of the plume 28.

However, it is considered that reflected lights of the YAG laser beams are changed by a state of the wall 26 on the front surface of the keyhole 25. When a state of the wall 26 on the front surface of the keyhole 25 varies with jetting of the zinc metallic vapor 27, the reflected lights of laser beams varies correspondingly. As this phenomenon occurs inside the keyhole 25 in the vicinity of the interface of the steel sheet,

the phenomenon cannot be caught by the sensor 6b that an observation angle is at a low level, but the phenomenon can be caught by the sensor 6a that an observation angle is at a high level.

Accordingly, it is necessary to set an angle in installing the sensor 6a within the range of an angle that a variation state of the wall 26 on the front surface of the keyhole 25 can be caught by the reflected lights. Actually, the angle is in the range of not interfacing with laser beams irradiated on the welding part and of being capable of catching the variation state of the wall 26 on the front surface of the keyhole 25 by the reflected lights, namely in the range of an angle of elevation 45 degrees to 70 degrees. It is to be noted that a further optimum angle within the range of this angle is decided in correspondence to a welding condition such as a plate thickness, an inter-sheet gap, power of laser beams, a focal position, or the like. In this embodiment, as shown in Fig. 1, the angle of elevation is 60 degrees.

Further, as shown in Fig. 7, when the zinc-plated steel sheets do not come into appropriate contact with each other in the butt part 20 and a slight gap 30 is caused, a metal melted in the keyhole 25 flows into the gap 30. Therefore, a defective welding which is called an under-filled state 31 occurs. The occurrence of the under-filled state 31 can be caught by the sensor 6b at a low level of the observation angle.

Next, a processing for detecting porocity by the monitoring system of the present invention will be described with reference to a flowchart of Fig. 8 and Figs. 9 to 12. Data such as a waveform, etc. shown in Figs. 9 to 12 are obtained as a result of measurement based on a following welding condition (basic welding condition). An output of the YAG laser is 3 Kw at a processing point. The zinc-plated steel sheets having thickness 0.8 mm were used, respectively. Welding speed is 4.5 m/min.

A flowchart of Fig. 8 shows a procedure of the monitoring method of the present invention. As shown in Fig. 6, when the

YAG laser beams are irradiated on the butt part 20 of the zinc-plated steel sheet, the irradiated part is melted by receiving energy of laser beams. As the melted metal is at a very high temperature, visible lights, infrared lights, reflected lights of YAG laser beams, or the like are radially released from the keyhole 25 and the plume 28. The sensors 6a and 6b enter these lights and convert the lights into an electric signal. The converted electric signal is stored in a storage device (not shown) of the personal computer 7E (refer to Fig. 4) (S1).

Fig. 9 is a waveform chart (converted by the photodiode 9) of an electric signal obtained from reflected lights of the YAG laser lights during welding under a basic welding condition. The waveform chart of this electric signal is prepared at sampling frequency 20KHz. In this waveform chart, a y-axis represents a signal intensity and an x-axis represents a time. Further, YH denotes a temporal variation condition of reflected lights caught by the sensor 6a at a high level of the observation angle. YL denotes a temporal variation condition of reflected lights caught by the sensor 6b at a low level of the observation angle. This chart shows waveforms of a "non-defective product" normally welded, a "porocity product" in which an occurrence of porocity is excessive, and an "under-filled product" in which an under-filled state is caused. In case of the under-filled product, a shape of waveforms apparently differs from a case of a non-defective product. Therefore, it is easy to determine as the under-filled product. However, as in case of the porocity product, a difference in the shape of waveforms is not seen by comparison with a case of the non-defective product, it is difficult to determine as the porocity product.

Fig. 10 is a waveform chart (converted by the photodiode 8) of an electric signal obtained from visible lights of the keyhole 25 and the plume 28 during welding under a basic welding condition. The waveform chart is also prepared at sampling frequency 20KHz. In this waveform chart, a y-axis represents a signal intensity and an x-axis represents a time. Further,

YH denotes a temporal variation condition of visible lights caught by the sensor 6a at a high level of the observation angle. YL denotes a temporal variation condition of visible lights caught by the sensor 6b at a low level of the observation angle. This chart shows waveforms of a "non-defective product" normally welded, a "porocity product" in which an occurrence of porocity is excessive, and an "under-filled product" in which an under-filled state is caused. In case of the under-filled product, a shape of waveforms apparently differs from a case of a non-defective product. Therefore, it is easy to determine as the under-filled product. However, as in case of the porocity product, a difference in the shape of waveforms is not seen by comparison with a case of the non-defective product, it is difficult to determine as the porocity product.

In this manner, it is difficult to differentiate between the non-defective product and the porocity product only by examining a temporal intensity change state of each of the reflected lights and the visible lights by each of the sensors 6a and 6b. For this reason, the waveforms of only the YH indicating the temporal variation condition of reflected lights caught by the sensor 6a at a high level of the observation angle are taken out among the waveforms stored in the storage device, and this waveform is subjected to a FFT (fast Fourier transform) signal intensity calculation (S2).

Fig. 11 is a waveform chart obtained as a result of subjecting the waveform of the YH shown in Fig. 9 to the FFT signal intensity calculation. In this waveform chart, a y-axis represents a relative signal intensity and an x-axis represents a frequency. A relative signal intensity denotes an amount indicating to what extent signal components of respective frequencies are included, and this relative signal intensity does not have unit. As is apparent from this chart, if the FFT signal intensity calculation is carried out, a difference in a distribution of the relative signal intensity is caused between the non-defective product and the porocity product. In other words, in the non-defective product, a peak part of the

relative signal intensity exists in the vicinity of 100 Hz to 500 Hz, but in the porocity product, a peak part of the relative signal intensity exists in the vicinity of 0 Hz to 1000 Hz. The quality monitoring method of the present invention differentiates this difference as follows:

Among the waveform of Fig. 11 obtained as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, the total value of the signal intensity between 605 Hz and 650 Hz is calculated (S3). If the total value exceeds 170,000 set as a reference value (S4, Yes), it is determined that an occurrence of porocity is excessive (S5), and if not exceeding 170,000 (S4, No), it is determined that an occurrence of porocity is within the normal range (S6). It is to be noted that a result of determining an occurrence of porocity (not shown in the flowchart) is displayed on the display 7F.

Next, from a feature amount of waveforms of Fig. 1 obtained as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, a Maharanobis distance is calculated (S7). This Maharanobis distance represents by a distance to what extent a feature amount (location) of a waveform of the observed workpiece is away from a normalized reference space obtained from a feature amount of waveforms of a non-defective product. According to the acquired Maharanobis distance, a distribution chart as shown in Fig. 12 is prepared. For example, as shown in Fig. 12, the feature amount (location) obtained from the waveform chart of Fig. 11 is written in a graph that a y-axis is a FFT signal intensity and an x-axis is a Maharanobis distance in logarithmic representation, and the products are distributed in accordance with the feature amount of each workpiece.

If the Maharanobis distance exceeds a reference value 1000 based on this distribution chart (S8, Yes), it is determined that an under-filled state occurs (S9), and if not exceeding that (S8, No), it is determined that the under-filled state does not occur (S10).

In the above embodiment, whether or not an occurrence of

porocity is excessive was determined based on a total value of a signal intensity of a specified frequency band, but as is apparent from the distribution chart of Fig. 12, the porocity products are distributed in a region that the Maharanobis distance is 2 or less and the signal intensity is 1700.0 or more, and similarly to a case where an occurrence of the under-filled product is determined, from the feature amount of waveforms of Fig. 11 obtained as a result of subjecting the FFT (fast Fourier transform) signal intensity calculation, the Maharanobis distance and the signal intensity of the specified frequency band are calculated, and further it is determined to which region the distance and signal intensity belong, so that it can be determined whether or not an occurrence of porocity is excessive.

Incidentally, in the above embodiment, a description was given on a case that welding is performed under condition that a plate thickness is 0.8 mm and a welding speed is 4.5 m/min, but the quality monitoring method and the quality monitoring system of the present invention can be applied to the other welding speed and plate thickness. When the welding speed and plate thickness differ from the above-mentioned welding condition, a specified frequency for determining an occurrence of porocity is varied. The reason is that, if the welding speed or the plate thickness is varied, with this variation, an effective specified frequency for determining an occurrence of the welding state of porocity is also varied. In order to maintain accuracy in determining an occurrence of porocity, an optimum frequency in determining an occurrence of porocity exists of itself according to the welding speed or plate thickness.

The following experiment is conducted as to how this specified frequency is varied to always accurately determine an occurrence of porocity by a variation of the welding speed or the plate thickness. Zinc-plated steel sheets having plate thicknesses 0.8 mm, 1.0 mm and 1.2 mm are used as workpieces, and two steel sheets are lap-welded. The welding speed was

varied between 3.0 m/min and 5.0 m/min. An output of the YAG laser was 3 Kw at a processing point and this output was fixed.

First, the case that a plate thickness is varied will be described. In this experiment, the welding speed was fixed at 3.5 m/min and the total of two plate thicknesses was varied between 1.6 mm and 2.4 mm. For example, if the porocity occurred in case of the total plate thickness 2.4 mm, the signal intensity of a frequency band of 0 Hz to 500 Hz was prone to increase. When the total plate thickness is decreased, the frequency band that the signal intensity increases was enlarged. A result of this experiment is shown in Fig. 13.

As shown in Fig. 13, when the total plate thickness is 1.6 mm, the signal intensity of the frequency band of 0 Hz to 1000 Hz increases, and when the total plate thickness is 1.8 mm, the signal intensity of the frequency band of 0 Hz to 800 Hz increases. Further, when the total plate thickness is 2.0 mm, the signal intensity of the frequency band of 0 Hz to 700 Hz increases, and when the total plate thickness is 2.4 mm, the signal intensity of the frequency band of 0 Hz to 500 Hz increases. Accordingly, an occurrence of porocity is determined in accordance with which frequency band is used, depending on what mm the total plate thickness is. Incidentally, as shown in Fig. 13, a relation between the total plate thickness and the frequency is stored in the storage device of the measuring device 7.

Next, the case where the welding speed was varied will be described. In this experiment, when the total plate thickness is 1.6 mm, the welding speed was varied between 3.0 m/min and 5.0 m/min, and further when the total plate thickness is 2.0 mm, the welding speed was varied between 3.0 m/min and 5.0 m/min. In case of any plate thickness also, as the welding speed is faster, the frequency band that the signal intensity increases decreased. A result of this experiment is shown in Fig. 14.

As shown in Fig. 14, when the total plate thickness is 1.6 mm, the signal intensity of the frequency band of 0 Hz to

1000 Hz increases at the welding speed 3.5 m/min, and the signal intensity of the frequency band of 0 Hz to 800 Hz increases at the welding speed 4.0 m/min. Further, when the total plate thickness is 2.0 mm, the signal intensity of the frequency band of 0 Hz to 700 Hz increases at the welding speed 4.5 m/min, and the signal intensity of the frequency band of 0 Hz to 600 Hz increases at the welding speed 5.0 m/min.

Further, when the total plate thickness is 2.0 mm, the signal intensity of the frequency band of 0 Hz to 800 Hz increases at the welding speed 3.0 m/min, and the signal intensity of the frequency band of 0 Hz to 700 Hz increases at the welding speed 3.5 m/min, and the signal intensity of the frequency band of 0 Hz to 600 Hz increases at the welding speed 4.0 m/min.

Accordingly, an occurrence of porocity is determined in accordance with which frequency band is used, depending on what m/min the welding speed is. Incidentally, a relation between the total plate thickness and the frequency as shown in Fig. 13 and a relation between the total plate thickness and the welding speed as shown in Fig. 14 are stored in the storage device of the measuring device 7 as Table as shown in Fig. 15. As shown in Fig. 15, the condition that the welding speed exists indicates that an effective frequency for determining an occurrence of porocity is stored. For example, when plate thickness t1 of an upper plate is 1.2 mm, plate thickness t2 of a lower plate is 0.8 mm, and a welding speed is 3.5 m/min, as shown in Fig. 14, the welding speed 3.5 m/min and the frequency band 0 Hz to 800 Hz at the total plate thickness 2.0 mm is used. Further, when plate thickness t1 of an upper plate and plate thickness t2 of a lower plate are 0.8 mm, and a welding speed is 5.0 m/min, as shown in Fig. 14, the welding speed 5.0 m/min and the frequency band 0 Hz to 600 Hz at the total plate thickness 1.6 mm is used.

As described above, the effective frequency for determining an occurrence of porocity varies based on variations of the plate thickness and the welding speed. The reason is that it can also be considered that the variation is

caused by a difference in a shape of a keyhole occurred in the welding part during welding.

As shown in Fig. 16, when the YAG laser beams are hit, a material melts, i.e., a keyhole occurs. The shape of the keyhole varies depending on a plate thickness and a welding speed. For example, in the shape of the keyhole, when the plate thickness increases, a depth H of the keyhole increases to form an elongated shape. Accordingly, an aspect ratio H/D calculated from the depth H of the keyhole and a width D of the keyhole increases. Further, in the shape of the keyhole, when the welding speed increases, the width D of the keyhole decreases, to form an elongated shape in this case also. Accordingly, the aspect ratio H/D calculated from the depth H of the keyhole and the width D of the keyhole increases.

As shown in Figs. 13 and 14, when the plate thickness increases and the welding speed increases also, the effective frequency for determining an occurrence of porocity lowers. It is considered that the reason is as follows: As described above, when the plate thickness increases and the welding speed increases also, the aspect ratio H/D increases. As a result, the shape of the keyhole becomes elongated and a resonance frequency of the keyhole lowers. As a result, the frequency band that the signal intensity increases lowers.

Accordingly, the shape of the keyhole is recognized by a CCD camera, to obtain the aspect ratio H/D, whereby the effective frequency for determining an occurrence of porocity may be obtained.

(Second Embodiment)

Next, a second embodiment will be described. In the first embodiment, only the occurrence of porocity was determined, but in the second embodiment, further, an occurrence of a welding state of an under-filled state or a non-welded state is accurately determined.

Incidentally, in the second embodiment also, the

arrangement of the quality monitoring system of the laser welding part is quite same with one shown in Figs. 1 to 4. Description of the arrangement is omitted. Incidentally, in the second embodiment, the personal computer 7E shown in Fig. 4 has a function as a storing means; a function as a signal intensity calculating means which calculates a signal intensity in a first frequency band for detecting an occurrence of an under-filled state, a signal intensity in a second frequency band for detecting an occurrence of porocity, and a signal intensity in a third frequency band for detecting an occurrence of a non-welded state; a function as a weld quality determining means for determining an occurrence of a welding state of the under-filled state, the porocity and the non-welded state; and a function as a dividing means for dividing a variation per hour of an electric signal with respect to the stored one welding part into a plurality of areas on a time-series basis.

A process of detecting the welding state of the under-filled state, the porocity and the non-welded state by a monitoring system according to the present invention will be described with reference to a flowchart of Fig. 18 and Figs. 19 to 25. Waveform data shown in Figs. 19 to 21 has been obtained as a measured result based on the following welding condition (basic welding condition). An output of the YAG laser is 3 Kw at a processing point. A zinc-plated steel sheet having thickness 0.8 mm was used. A welding speed is 4.5 m/min.

In the second embodiment, the welding state of the non-welded state can be detected also. The non-welded state means an incomplete weld that a desirable welding intensity cannot be obtained. As shown in Fig. 17, the non-welded state occurs by a cause that, when two steel sheets are lap-welded, an inter-sheet gap 40 in a butt part of vertical steel sheets is too large. Because if the gap 40 is too large, heat does not sufficiently conduct to a lower steel sheet and the welding part is not sufficiently melted.

A flowchart of Fig. 18 shows a procedure of the monitoring method according to the present invention. As shown in Fig.

6, when the YAG laser beams are irradiated on the butt part 20 of the zinc-plated steel sheet, the irradiated part is melted by receiving energy of laser beams. As the melted metal is at a very high temperature, visible lights, infrared light or reflected lights of the YAG laser beams are radially emitted from a keyhole 25 and a plume 28. The sensor 6a and the sensor 6b enter these lights and converts into an electric signal. The converted electric signal is stored in a storage device (not shown) of the personal computer 7E (refer to Fig. 4) in each welding part (S21).

Figs. 19 and 20 show a waveform chart of an electric signal (which is converted by the photodiode 9) obtained from reflected lights of the YAG laser beams when welding is performed under a basic welding condition. The waveform chart of these electric signals is prepared at sampling frequency 20 KHz. In the waveform charts, a y-axis denotes a signal intensity (voltage value) and an x-axis denotes a time. These waveform charts denote a temporal variation situation (variation per hour) of reflected lights in a certain welding part which is sensed by the sensor 6a of which an observation angle is at a high position. Fig. 19 shows waveforms of the "non-defective product" in which a normal welding was performed and the "non-welded product", which welding was incomplete, and Fig. 20 shows waveforms of the "under-filled product" in which an under-filled state occurred and the "porocity product" in which an occurrence of porocity is excessive. Contrasting these waveform charts, as only a waveform shape of the under-filled product differs apparently from the other waveform shapes, it is easy to determine that the product is in an under-filled state. However, the waveform shapes of the non-welded product and the porocity product does not differ apparently from the waveform shape of the non-defective product. For this reason, it is difficult to make sure of these welding states from the waveform charts.

In this manner, it is difficult to differentiate the non-defective product and the non-welded product from the non-defective product and the porocity product only by

examining a temporal intensity variation state of reflected lights. For this reason, a waveform indicating the temporal intensity variation state of reflected lights at one welding part sensed by the sensor 6a of which the observation angle is at a high position is taken out from among the waveforms stored in the storage device, and this waveform is subjected to a FFT (fast Fourier transform) signal intensity calculation (S22).

Fig. 21 is a waveform chart obtained resultantly by subjecting each waveform shown in Figs. 19 and 20 to the FFT signal intensity calculation. In this waveform chart, a y-axis represents a signal intensity and an x-axis represents a frequency. The signal intensity means an amount (area) indicating to what extent signal components of each frequency are included, and this signal intensity does not have unit.

As is apparent from this chart, when the FFT signal intensity calculation is carried out, a difference in a distribution of the signal intensity is caused by each of the "non-defective product", the "non-welded product", the "under-filled product" and the "porocity product". In the quality monitoring method of the present invention, this difference is differentiated as follows:

Among the waveforms of Fig. 21 obtained resultantly by carrying out the FFT (fast Fourier transform) signal intensity calculation, a frequency band of 0 to 1000 Hz is set as a first frequency band for detecting an occurrence of the under-filled state, and further similarly, a frequency band of 0 to 1000 Hz is set as a second frequency band for detecting an occurrence of the porocity. The reason why setting such the frequency bands is that the occurrence of the under-filled state or porocity can definitely be detected in this frequency band according to a result of the experiment. Here, the first and second frequencies are identical, but it is necessary that the effective frequency band for detecting an occurrence of porocity is varied in accordance with a plate thickness or a welding speed, as mentioned above in the first embodiment. Accordingly, the second frequency band for detecting an

occurrence of porocity is varied, for example, from 0 to 600 Hz according to the plate thickness or the welding speed.

Successively, a frequency band of 3000 to 6000 Hz is set as a third frequency band for detecting an occurrence of a non-welded state. The reason is that, as can be seen from Fig. 21, when the non-welded state occurred, the signal intensity of this frequency band is prone to increase more than the signal intensity when the under-filled state or the porocity occurred. Further, the reason why this frequency band is set is that the occurrence of the non-welded state can definitely be detected in this frequency band according to a result of the experiment.

The signal intensity of these frequency bands is obtained and is plotted in a biaxial coordinate system provided virtually as shown in Fig. 22. This biaxial coordinate system is a coordinate system that an x-axis denotes a signal intensity in the frequency band (the first frequency band and the second frequency band) of 0 Hz to 1000 Hz, and a y-axis denotes a magnitude of a signal intensity in 3000 Hz to 6000 Hz (the third frequency band), respectively.

For example, in case of the under-filled state, the waveform as shown in Fig. 21 can be obtained, and an area obtained from the waveform of the frequency band of 0 Hz to 1000 Hz and an area obtained from the waveform of the frequency band of 3000 Hz to 6000 Hz are obtained with respect to this waveform, and each area is plotted on the x-axis and the y-axis. As shown in Fig. 22, it is found by this plot that the under-filled product (mark △) is prone to distribute in an area where the signal intensities of the x-axis and the y-axis of the biaxial coordinate system are small. Similarly, it is found that the porocity product (mark □) is prone to distribute in an area where the signal intensity of the y-axis of the biaxial coordinate system is small and the signal intensity of the x-axis of the biaxial coordinate system is large, and further that the non-welded product (mark ◇) is prone to distribute in an area of the entire x-axis where the signal intensity of the y-axis of the biaxial coordinate system is large. Further,

it is found that the non-defective product (mark ○) is prone to distribute in an area where the signal intensity of the y-axis of the biaxial coordinate system is small and the signal intensity of the x-axis of the biaxial coordinate system is about intermediate.

An examination is made in a plurality of welding products as to how the under-filled product, the porocity product, the non-welded product and the non-defective product distribute in the above-described biaxial coordinate system. As a result, it was found that each distribution area is classified as shown in Fig. 23. Further, when the phenomenon of the under-filled product, the porocity product and the non-welded product occurred at one welding part partially in combination, it is considered that the under-filled product, the porocity product and the non-welded product distribute in the vicinity of a boundary of each area. For this reason, in the present invention, as shown in Fig. 24, a mixing area which is difficult to determine a type of a welding state is prescribed. Accordingly, an under-filled area, a non-defective area, a porocity area, a non-welded area and a mixing area exist in the virtual biaxial coordinate system. Incidentally, to what extent the mixing area has a width is determined in accordance with a result of the experiment or operations of the technique.

Incidentally, this virtual biaxial coordinate system is created by the personal computer 7E shown in Fig. 4, and these areas are not created actually as a two-dimensional plane. Further, the calculation results are virtually plotted in this biaxial coordinate system based on the calculation result of each signal intensity, but the plot is not actually carried out on the two-dimensional plane. The range of numeric values of the signal intensity forming each area is stored in the personal computer 7E, and the personal computer 7E can immediately determine which welding state occurs, or whether or not the product is non-defective, according to which area's range of numeric values the calculation result belongs to.

Return to the flowchart of Fig. 18, the signal intensity

of 0 to 1000 Hz and 3000 Hz to 6000 Hz is calculated with respect to the waveform shown in Fig. 21 to be obtained during welding (S23). It is determined which area shown in Fig. 24 the coordinates in the biaxial coordinate system specified by the calculated signal intensity of 0 to 1000 Hz and the calculated signal intensity of 3000 Hz to 6000 Hz belong to (S24).

If the coordinates belong to the preset area of the non-defective product (S24: YES), it is determined that the welding of the welding part is normally carried out (non-defective product) (S25). On the other hand, if the coordinates do not belong to the preset area of the non-defective product (S24: NO), it is determined which area out of the preset under-filled area, porocity area and non-welded area the coordinates belong to (S26).

If the coordinates belong to any area of the under-filled area, the porocity area and the non-welded area (S26: YES), a welding state in the belonging area occurs, and it is determined that the weld quality of the welding part is problematic (S27). Incidentally, although not shown in the flowchart, a display of the non-defective product or a display of an occurrence of any welding state appears on the display 7F. According to the above processes, the determination for the entire one welding part is terminated.

On the other hand, if the coordinates does not belong to any area of the under-filled area, the porocity area and the non-welded area, i.e., if the coordinates belong to the mixing area (S26: NO), as shown in Fig. 25, the welding part is divided into a plurality of areas, and it is determined again which welding state each area is in.

The re-determination as to which welding state each area is in is carried out according to the following procedure:

As mentioned above, a variation per hour of an electric signal output from the sensor 6a for one welding part is stored in the storage device of the personal computer 7E, and when determining again which welding state each area is in, the stored variation per hour of an electric signal is divided into

a plurality of areas on a time-series basis. For example, when a welding length of a certain welding part is 30 mm as shown in Fig. 25, the welding part is divided into five parts, for example, by 6 mm, and it is determined which welding state each of the divided areas is in, or whether or not the product is non-defective, according to the quite identical procedure to the above-mentioned procedure.

When a division of this area is adapted to the stored electric signal, as a welding speed is 4.5 m/min in the second embodiment, 0.4 sec is needed to weld a welding part of 30 mm. Accordingly, the electric signal at this welding part stored in the storage device is an electric signal corresponding to 0.4 sec. In order to divide this into five parts as above, this electric signal is divided on a time-series basis by 0.08 sec. This division is caused to obtain electric signals of five time bands such as a first time band of 0 to 0.08 sec, a second time band of 0.08 to 0.16 sec, a third time band of 0.16 to 0.24 sec, a fourth time band of 0.24 to 0.32 sec, and a fifth time band of 0.32 to 0.04 sec, at the welding part. Incidentally, it is desirable that the division is carried out in unit of about 1 mm to about 8 mm, and it is also necessary that the division is varied according to the circumstances in accordance with a shape of the welding part or desirable determination accuracy of the weld quality.

The electric signals of these time bands are taken out one by one from the storage device, and the waveforms of these five electric signals are subjected to the FFT (fast Fourier transform) signal intensity calculation (S28). The signal intensities of 0 to 1000 Hz and 3000 to 6000 Hz are calculated with respect to each waveform (S29). It is determined which area in the biaxial coordinate system shown in Fig. 24 the calculated signal intensities of 0 to 1000 Hz and the calculated signal intensities of 3000 to 6000 Hz exist in, respectively (S30). It is determined from the above processes that, for example, as shown in Fig. 25, the non-welded state occurs in the area (an area at a left end in Fig. 25) corresponding to

the first time band, the non-welded state occurs in the area (an area on the right thereof) corresponding to the second time band, and the product is non-defective in the residual third time band to fifth time band (an area till a right end of the residual).

Next, a ratio of the non-defective product to the welding part is calculated (S31). In the above-mentioned case, as any welding states occurred in two areas out of the areas divided by five, a ratio of the non-defective product becomes 60%.

If the number of areas which are determined as the non-defective product exceeds a necessary ratio (e.g., 70%) of the non-defective product which is preset with respect to the number of divided areas (S32: YES), it is determined that the welding part is non-defective as a whole (S33). The reason why such technology is used is that, when the welding length is set longer than the welding length demanded in designing by expecting an occurrence of the welding state such as the under-filed state, the porocity and the non-welded state at a certain welding part, if a calculated length of the non-defective welding part is longer than a welding length demanded in designing, it is not problematic on the weld quality if it is determined that the welding part is synthetically non-defective.

On the other hand, if the number of areas which are determined as the non-defective product does not exceed a necessary ratio (e.g., 70%) of the non-defective product which is preset with respect to the number of divided areas (S32: NO), the welding state such as the under-filled state, the porocity and the non-welded state exists at the welding part, and it is determined that the welding part is synthetically problematic in the weld quality (S34). Incidentally, although not shown in the flowchart, a display of the non-defective product as seen synthetically, or a display that the weld quality is synthetically problematic appears on the display 7F.

As described above, when it is determined that the welding quality is problematic in determining entirely a certain

welding part, if the welding part is determined again, it is possible to raise determination accuracy as compared with an evaluation method of only the entire welding part.

The above processes are carried out in real time at the same time as welding. Further, even if the above-described division determination is carried out, the determination is terminated until a next welding part is welded. If it is determined that the welding part is problematic in the weld quality finally, a paint is sprayed on the welding part. Tens of welding parts exist in one workpiece, and it is easy to make a final inspection in a post-step by spraying a paint as above. In the final inspection, it is once determined visually by an operator whether or not a part sprayed with a paint is really problematic in the weld quality. When it is determined in the final inspection that the weld quality is problematic, the workpiece is conveyed to a back-up step to carry out a repair work.

Incidentally, the above processes were given on the case where the plate thickness or the welding speed is constant. As mentioned also in the first embodiment, an optimum frequency for determination of an occurrence of porocity exists of itself according to the plate thickness, the welding speed or the aspect ratio. Accordingly, in the second embodiment also, in the same manner as the first embodiment, the frequency (the second frequency band in the second embodiment) is varied according to the plate thickness, the welding speed or the aspect ratio. Incidentally, which frequency to be set according to the variation of the plate thickness, or which frequency to be set according to the variation of the welding speed was described in detail in the first embodiment, and description is omitted here.

As described above, in the second embodiment, as the occurrence of the welding state such as the porocity, the under-filled state and the non-welded state can be determined by the quite identical calculation process, it is not necessary to carry out each different complicated calculation process for

detecting the occurrence of each type of welding state unlike conventionally. Accordingly, a process load of the CPU for the calculation process is reduced.

Further, any welding state occurred in only a part of the welded parts can easily be determined by the technique of the division determination, and determination accuracy of the type of occurred welding state is raised conspicuously.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is an embodied structural diagram of a YAG laser welder equipped with a quality monitoring system according to the present invention;

[Fig. 2]

Fig. 2 is a conceptual diagram of the YAG laser welder equipped with the quality monitoring system according to the present invention;

[Fig. 3]

Fig. 3 is a diagram showing an embodied constitution inside a sensor;

[Fig. 4]

Fig. 4 is a diagram showing an embodied constitution of a measuring device shown in Fig. 2;

[Fig. 5]

Fig. 5 is a view for explaining a principle of detecting a weld quality;

[Fig. 6]

Fig. 6 is a view for explaining a principle of detecting the weld quality;

[Fig. 7]

Fig. 7 is a view for explaining a principle of detecting the weld quality;

[Fig. 8]

Fig. 8 is a flowchart showing a procedure of a monitoring method according to a first embodiment of the present invention;

[Fig. 9]

Fig. 9 is a waveform chart of an electric signal obtained from reflected lights of YAG laser beams during welding under a basic welding condition;

[Fig. 10]

Fig. 10 is a waveform chart of an electric signal obtained from visible lights of a keyhole and a plume during welding under a basic welding condition;

[Fig. 11]

Fig. 11 is a waveform chart obtained as a result of subjecting a waveform of YH shown in Fig. 9 to a FFT signal intensity calculation;

[Fig. 12]

Fig. 12 is a distribution chart drawn based on a Maharanobis distance acquired;

[Fig. 13]

Fig. 13 is a diagram showing a relation between a total plate thickness and an effective frequency for determining an occurrence of porocity;

[Fig. 14]

Fig. 14 is a diagram showing a relation between a total plate thickness, a welding speed and an effective frequency for determining an occurrence of porocity;

[Fig. 15]

Fig. 15 is a diagram showing one example of Table stored in a storage device of a measuring device;

[Fig. 16]

Fig. 16 is a diagram for explaining an aspect ratio of a keyhole caused in a welding part;

[Fig. 17]

Fig. 17 is a diagram for explaining a non-welded state;

[Fig. 18]

Fig. 18 is a flowchart showing a procedure of a monitoring method according to a second embodiment of the present invention;

[Fig. 19]

Fig. 19 is a waveform chart of an electric signal obtained from reflected lights of YAG laser beams during welding under a basic welding condition;

[Fig. 20]

Fig. 20 is a waveform chart of an electric signal obtained from reflected lights of YAG laser beams during welding under a basic welding condition;

[Fig. 21]

Fig. 21 is a waveform chart obtained as a result of subjecting an electric signal shown in Figs. 19 and 20 to a FFT signal intensity calculation;

[Fig. 22]

Fig. 22 is a diagram for explaining a distribution state of an under-filled product, a porocity product, a non-welded product and a non-defective product;

[Fig. 23]

Fig. 23 is a diagram showing an under-filled area, a porocity area, a non-welded area and a non-defective area which are prescribed in a biaxial coordinate system;

[Fig. 24]

Fig. 24 is a diagram for explaining a mixing area which is prescribed in the biaxial coordinate system; and

[Fig. 25]

Fig. 25 is a diagram for explaining a procedure of determining again which welding state each area is in.

[Description of the Reference Numerals]

1: YAG laser oscillator
2: optical fiber cable
3: collimator lens
4: light converging lens
5: workpiece
6a, 6b: sensors
7: measuring device
7A: amplifier
7B, 7D: A/D converters
7C: band-pass filter
7E: personal computer
7F: display
8, 9: photodiodes
10: dichroic mirror
11: interference filter
20: butt part
21: zinc-plated layer
22: steel
23: porocity
25: keyhole
26: wall
27: zinc metallic vapor
28: plume
30, 40: gaps
31: under-filled state
100: YAG laser welder

[Name of Document] ABSTRACT

[Abstract]

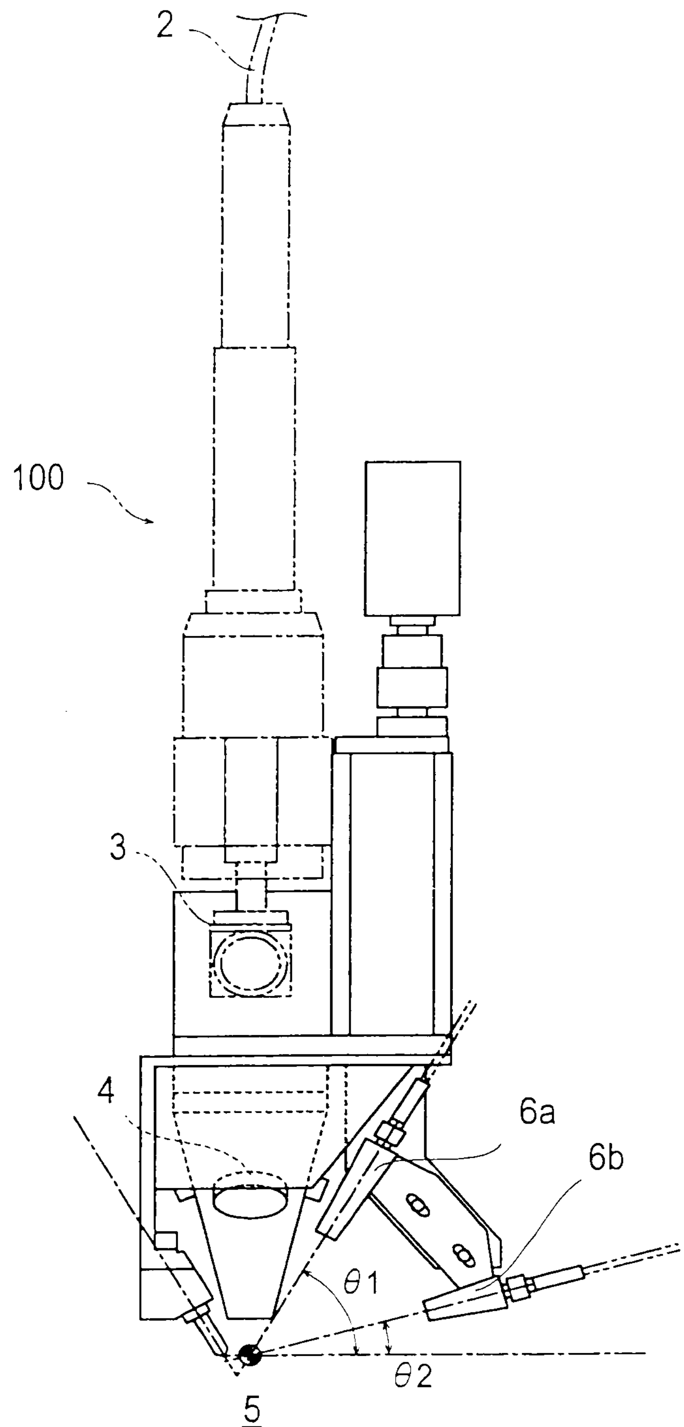
[Object] To detect reliably an occurrence of porocity of a laser welding part.

[Solving Means] Reflected lights of laser beams irradiated toward a welding part F of a workpiece 5 are detected by a sensor 6a and converted into an electric signal, and a measuring device 7 calculates a frequency distribution of the electric signal, to calculate a signal intensity in a specified frequency band out of the calculated frequency distribution. If the calculated signal intensity exceeds a preset reference value, it is determined that an occurrence of porocity is excessive, and if the calculated signal intensity does not exceed the reference value, it is determined that an occurrence of porocity is within a normal range.

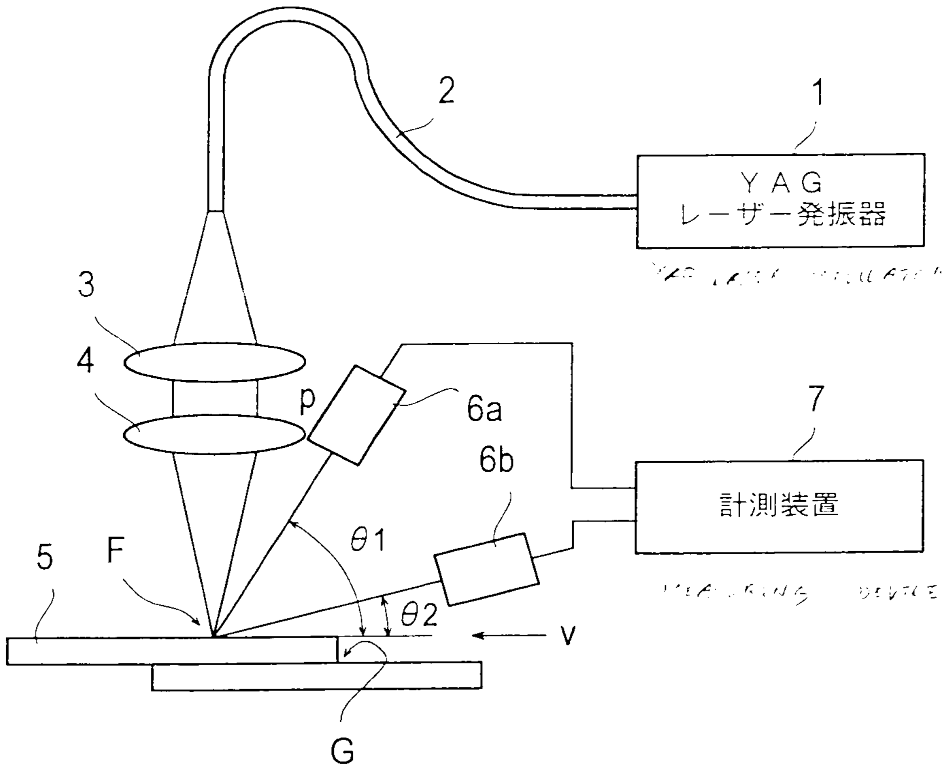
[Selected Figure] Fig. 2

【書類名】　図面

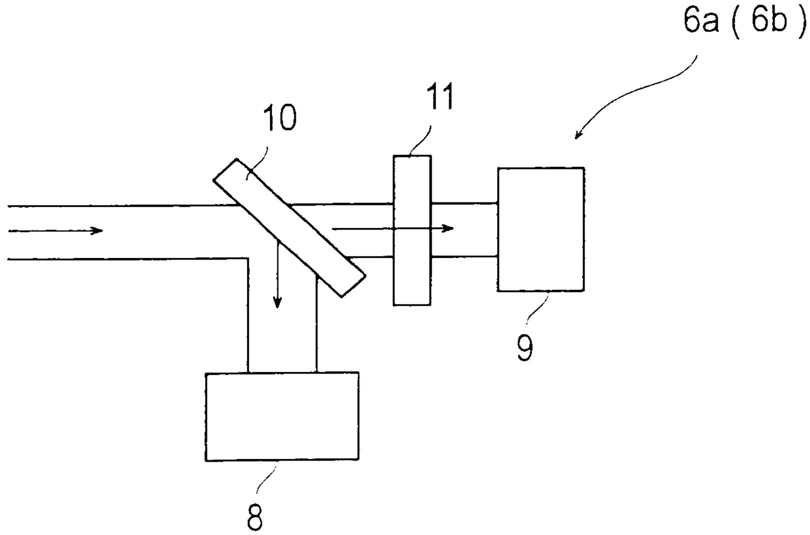
【図1】



【図２】

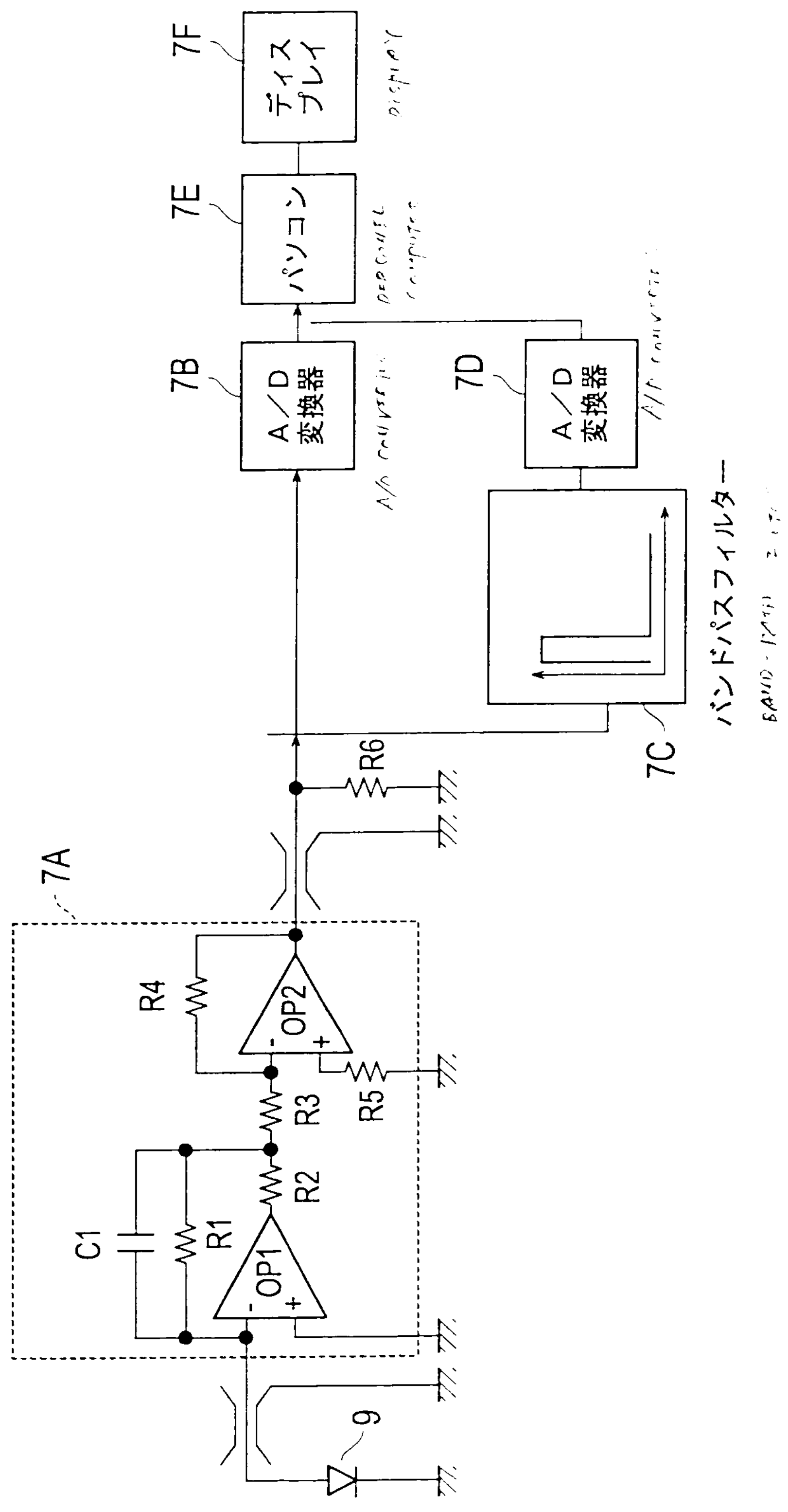


【図３】



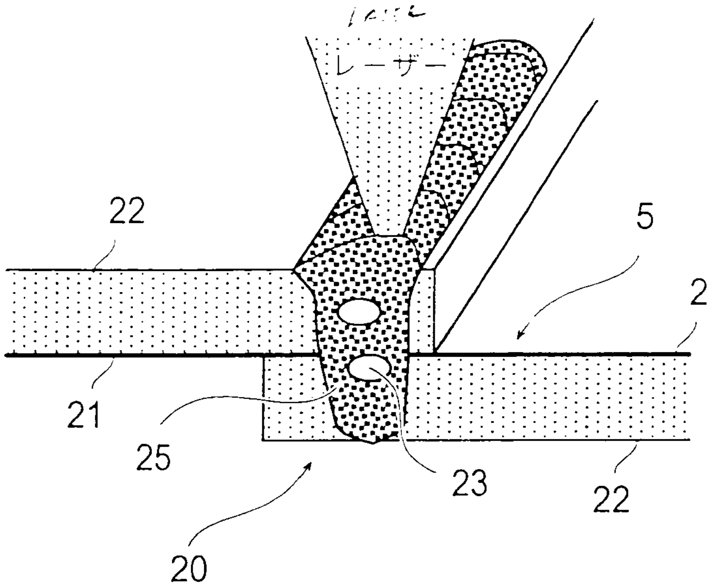
【図４】

[Fig. 4]


7F
ディスプレイ
DISPLAY
7E
パソコン
PERSONAL COMPUTER
7B
A／D 変換器
7D
A／D 変換器
バンドパスフィルター
BAND-PASS FILTER
7C
R6
7A
R4
OP2
R5
R3
R2
C1
R1
OP1
9

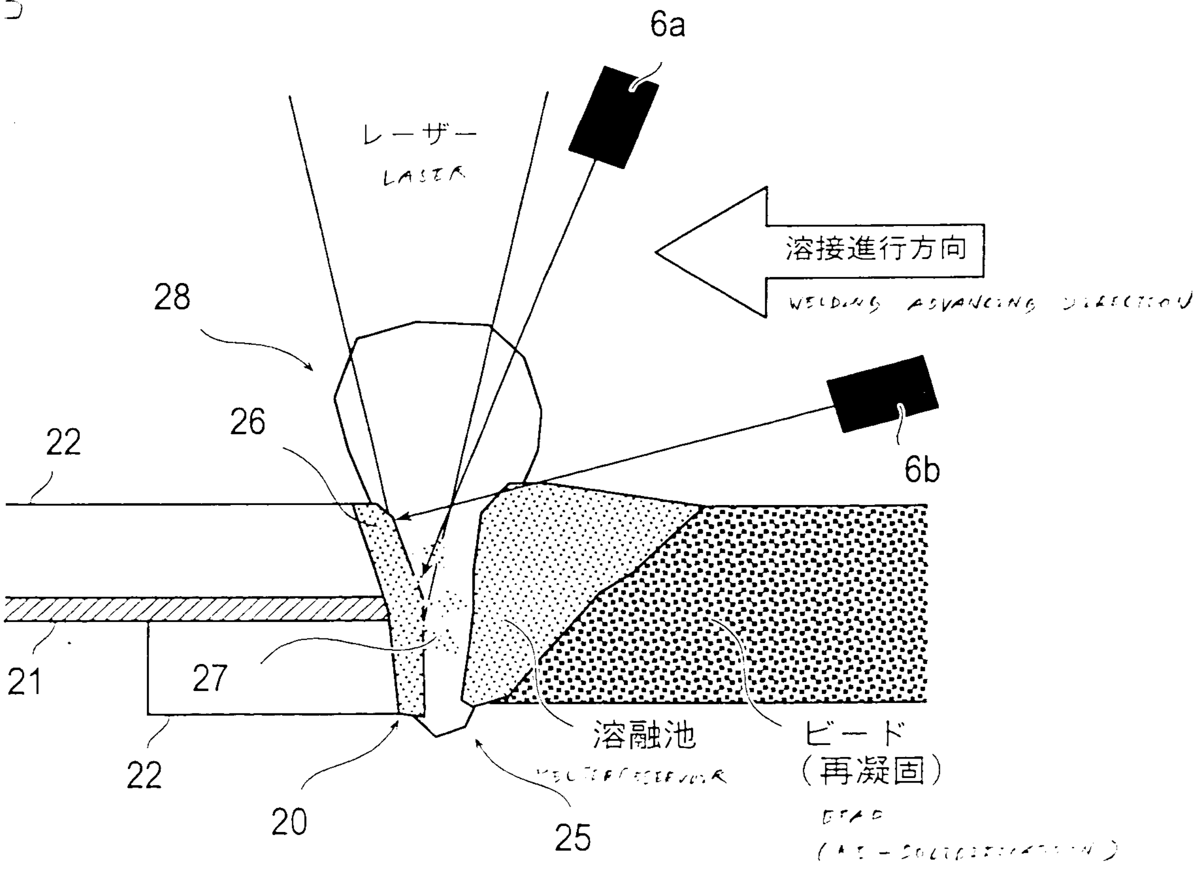
【図５】

[Fig.5]

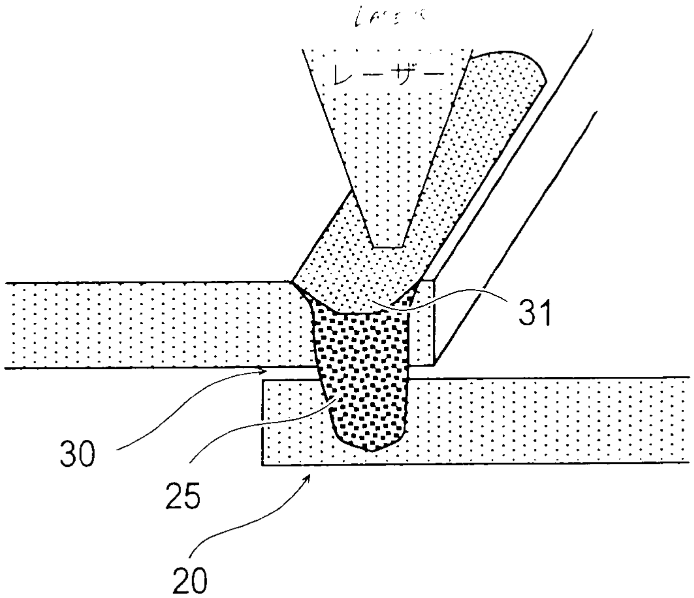


【図６】

[Fig.6]

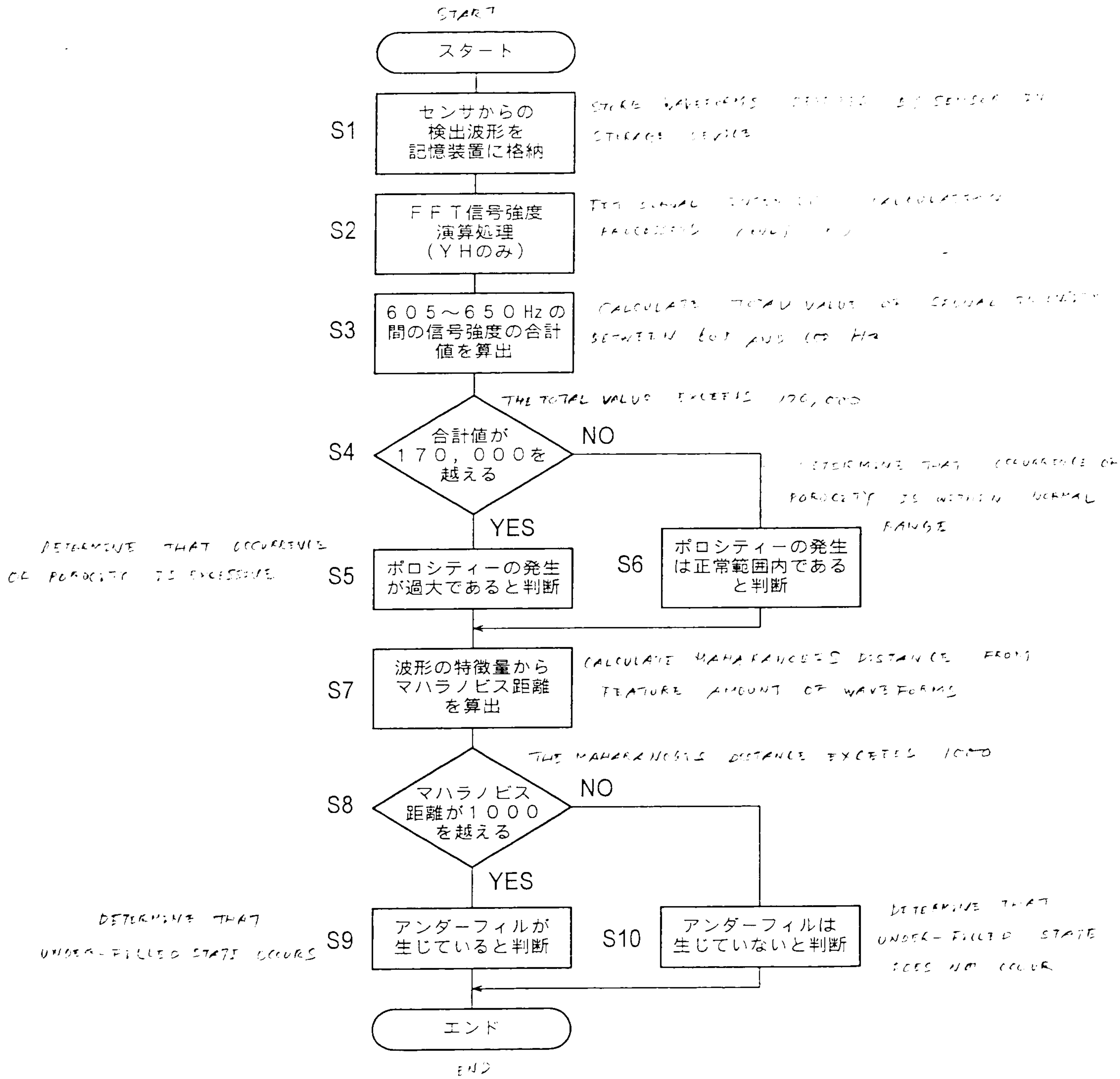


【図７】
[Fig 7]

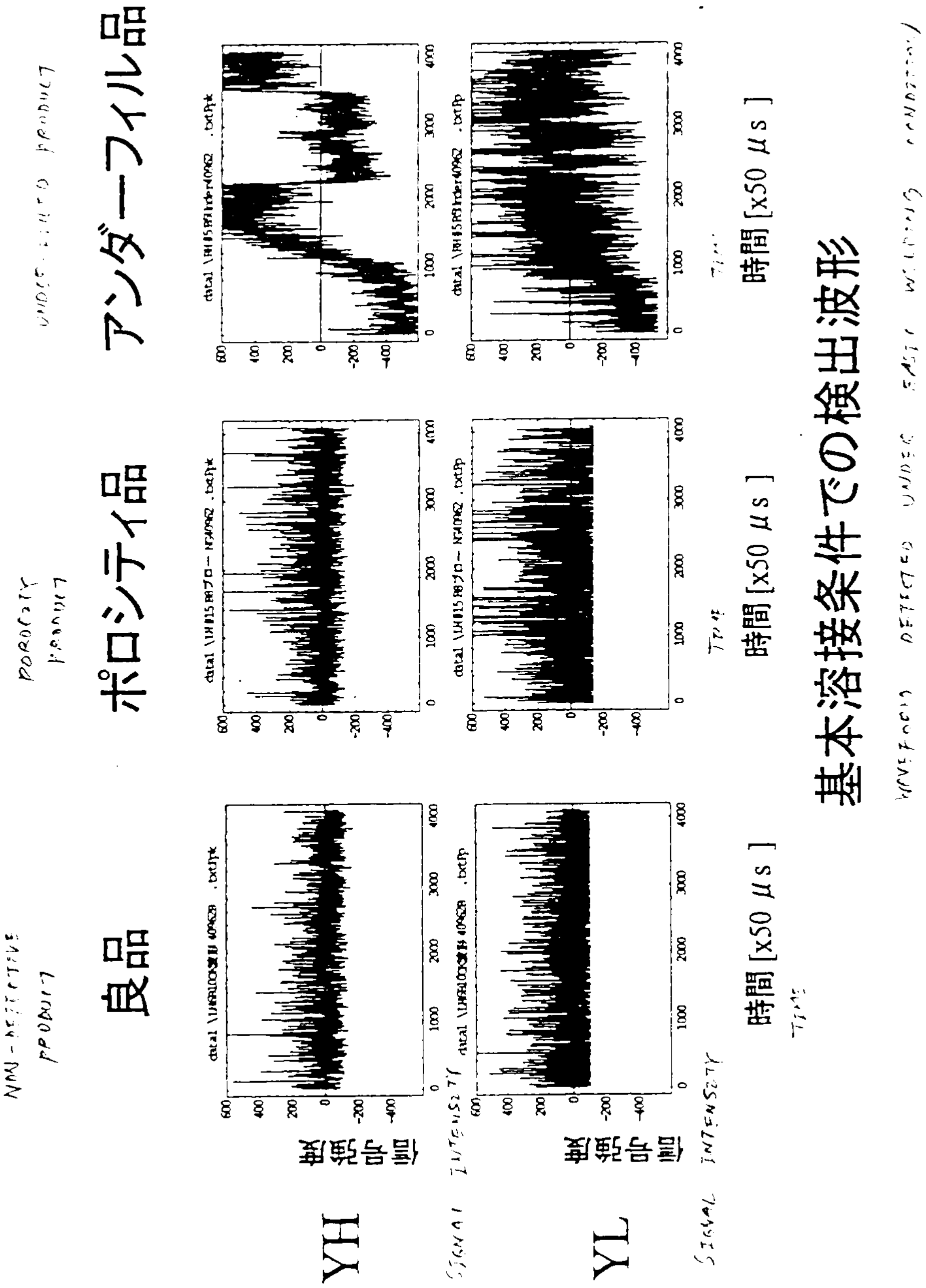


【図８】

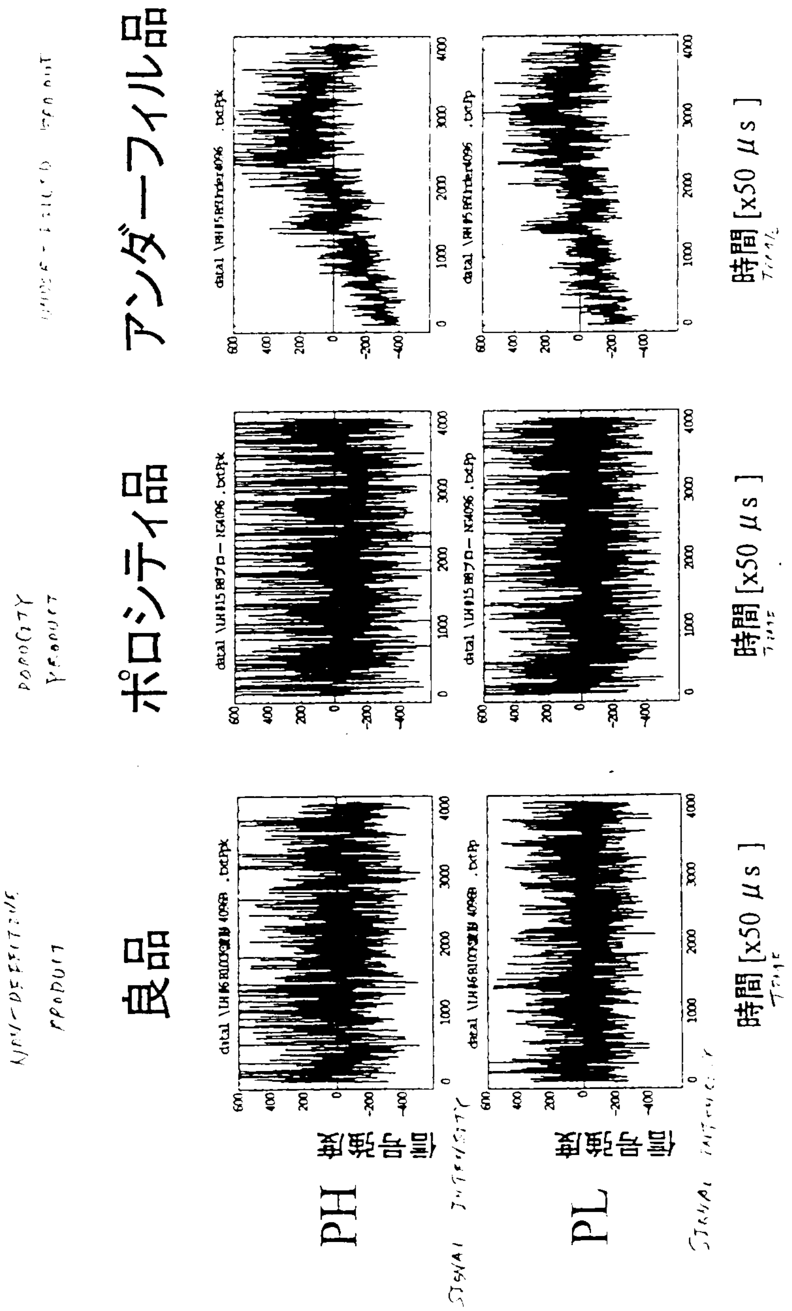
[Fig 8]


START
スタート
S1
センサからの検出波形を記憶装置に格納
STORE WAVEFORMS DETECTED BY SENSOR IN STORAGE DEVICE
S2
ＦＦＴ信号強度演算処理（ＹＨのみ）
FFT SIGNAL INTENSITY CALCULATION PROCESSING (ONLY YH)
S3
６０５～６５０Hzの間の信号強度の合計値を算出
CALCULATE TOTAL VALUE OF SIGNAL INTENSITY BETWEEN 605 AND 650 Hz
THE TOTAL VALUE EXCEEDS 170,000
S4
合計値が１７０，０００を越える
NO
YES
DETERMINE THAT OCCURRENCE OF POROCITY IS WITHIN NORMAL RANGE
S6
ポロシティーの発生は正常範囲内であると判断
DETERMINE THAT OCCURRENCE OF POROCITY IS EXCESSIVE
S5
ポロシティーの発生が過大であると判断
S7
波形の特徴量からマハラノビス距離を算出
CALCULATE MAHARANOBIS DISTANCE FROM FEATURE AMOUNT OF WAVEFORMS
THE MAHARANOBIS DISTANCE EXCEEDS 1000
S8
マハラノビス距離が１０００を越える
NO
YES
DETERMINE THAT UNDER-FILLED STATE OCCURS
S9
アンダーフィルが生じていると判断
S10
アンダーフィルは生じていないと判断
DETERMINE THAT UNDER-FILLED STATE DOES NOT OCCUR
エンド
END

【図９】

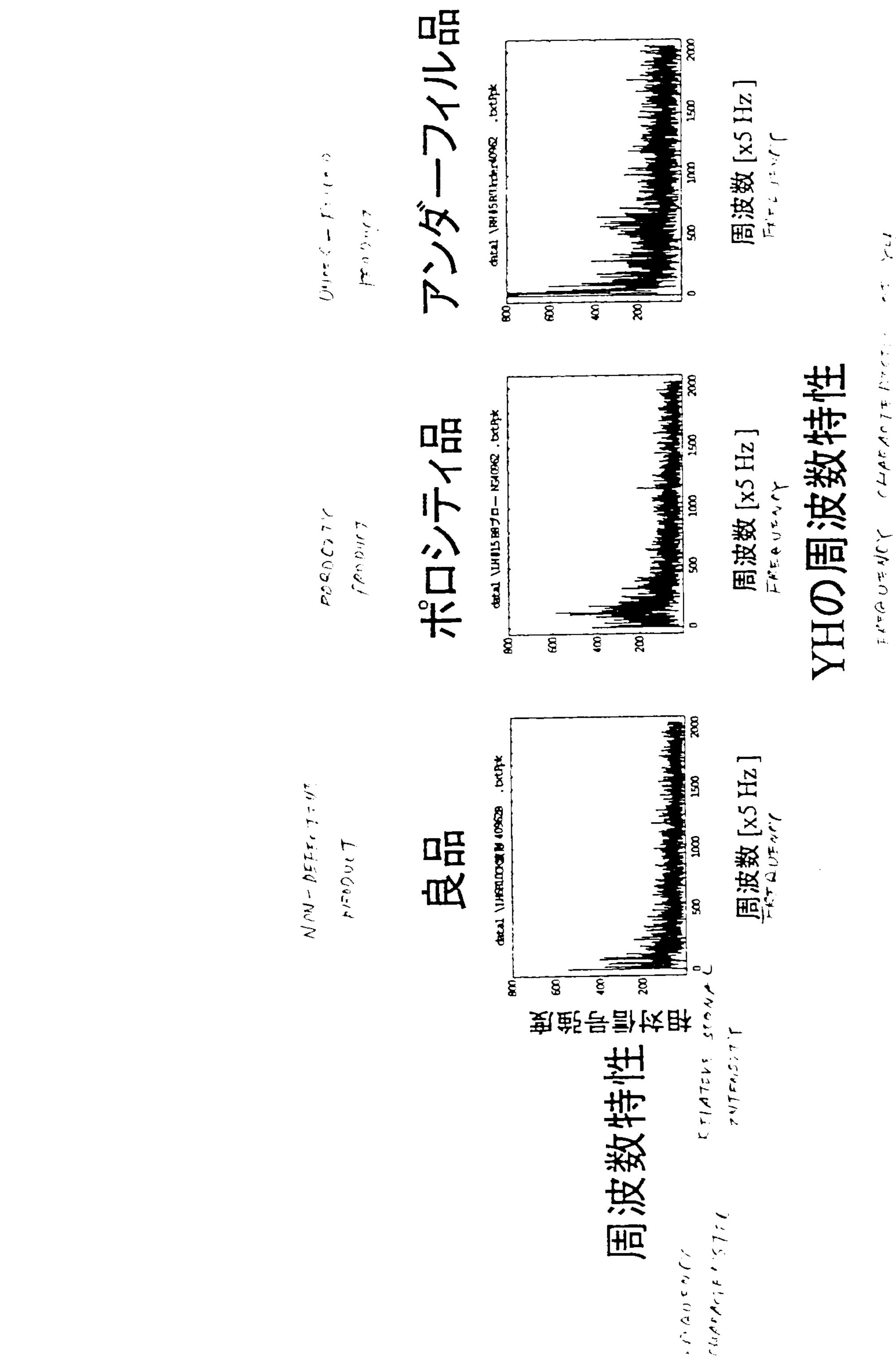

良品
ポロシティ品
アンダーフィル品
YH
YL
信号強度
信号強度
時間 [x50 μs]
時間 [x50 μs]
時間 [x50 μs]
SIGNAL INTENSITY
基本溶接条件での検出波形

【図１０】
[Fig. 10]



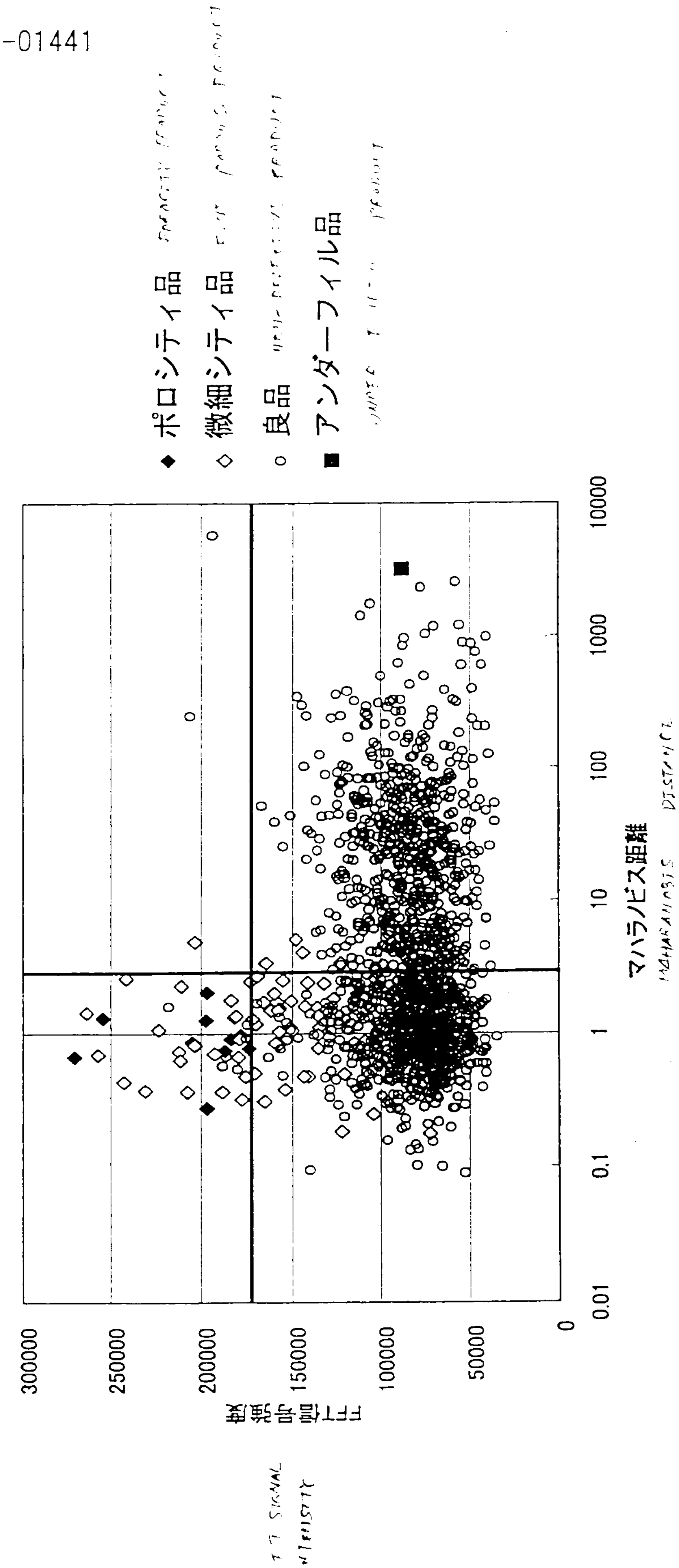
基本溶接条件での検出波形

【図１１】


周波数特性
相対信号強度
良品
ポロシティ品
アンダーフィル品
周波数 [x5 Hz]
周波数 [x5 Hz]
周波数 [x5 Hz]
YHの周波数特性

【図１２】

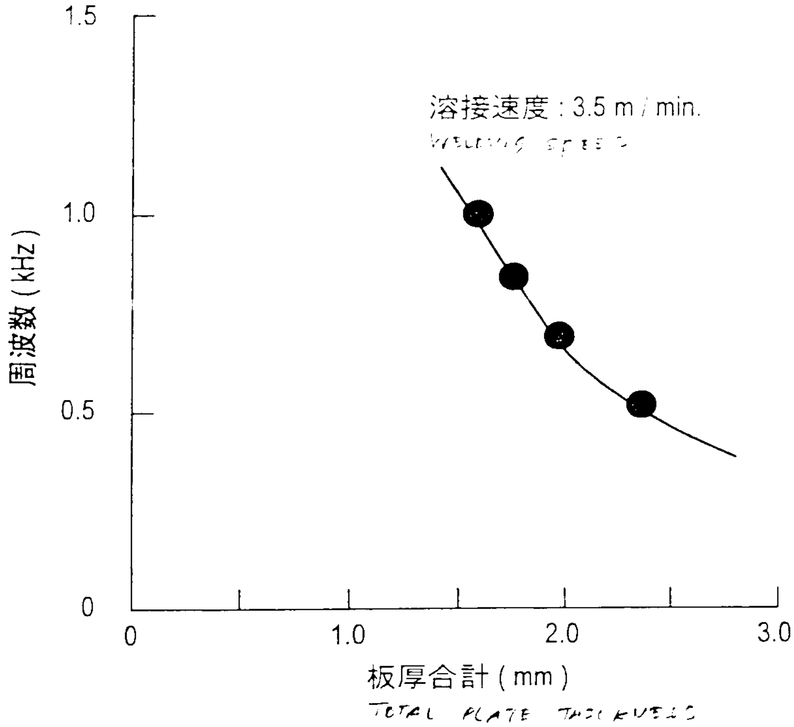
[FIG.12]



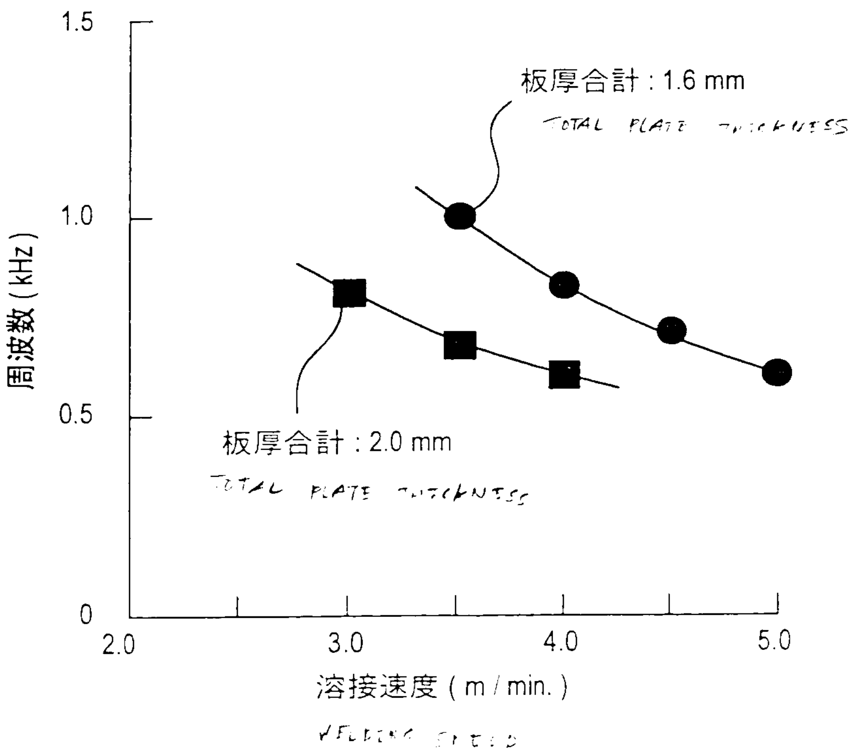
ポロシティとアンダーフィルの分離結果例

RESULTANT EXAMPLE OF SEPARATION OF POROSITY AND UNDER-FILLED STATE

【図１３】
[Fig. 13]



【図１４】
[Fig. 14]

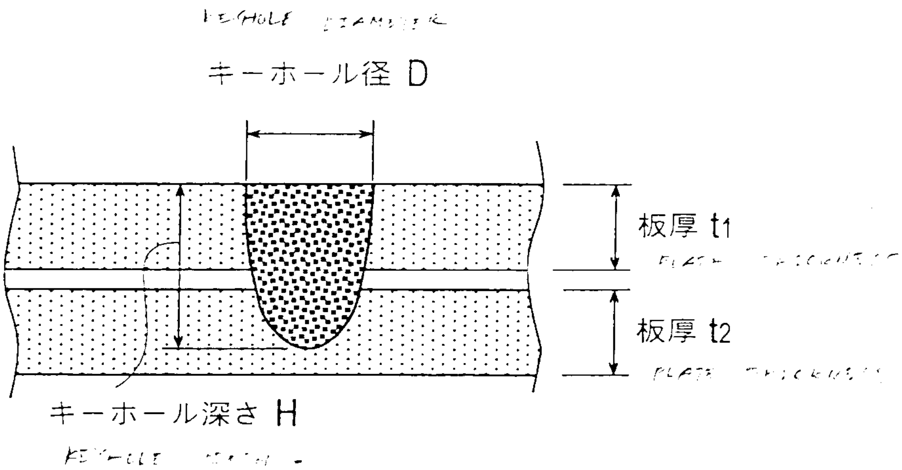


【図１５】
[Fig. 15]

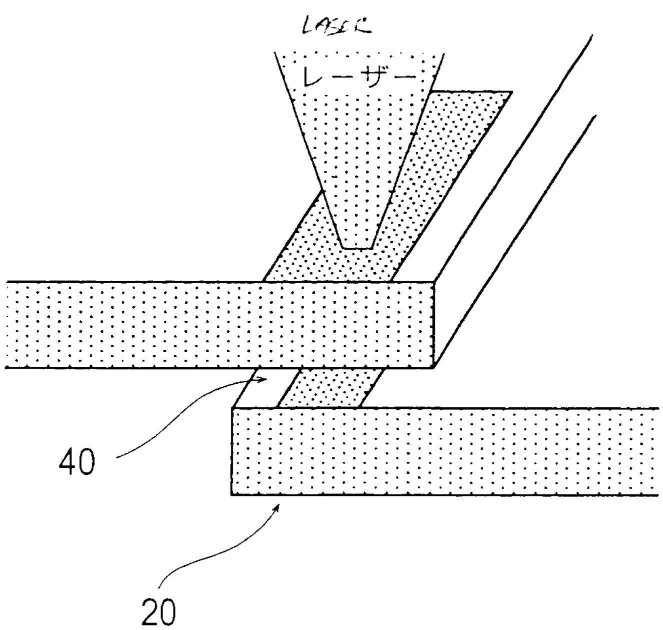
TABLE
テーブル

	LOWER PLATE \ UPPER PLATE	UPPER PLATE 上板 t_1		
	下板＼上板	0.8 mm	1.0 mm	1.2 mm
下板 t_2 LOWER PLATE	0.8 mm	3.5 m / min.	3.5 m / min.	3.5 m / min.
		4.0 m / min.		
		4.5 m / min.		
		5.0 m / min.		
	1.0 mm	3.5 m / min.		
	1.2 mm	3.0 m / min.		
		3.5 m / min.		3.5 m / min.
		4.0 m / min.		

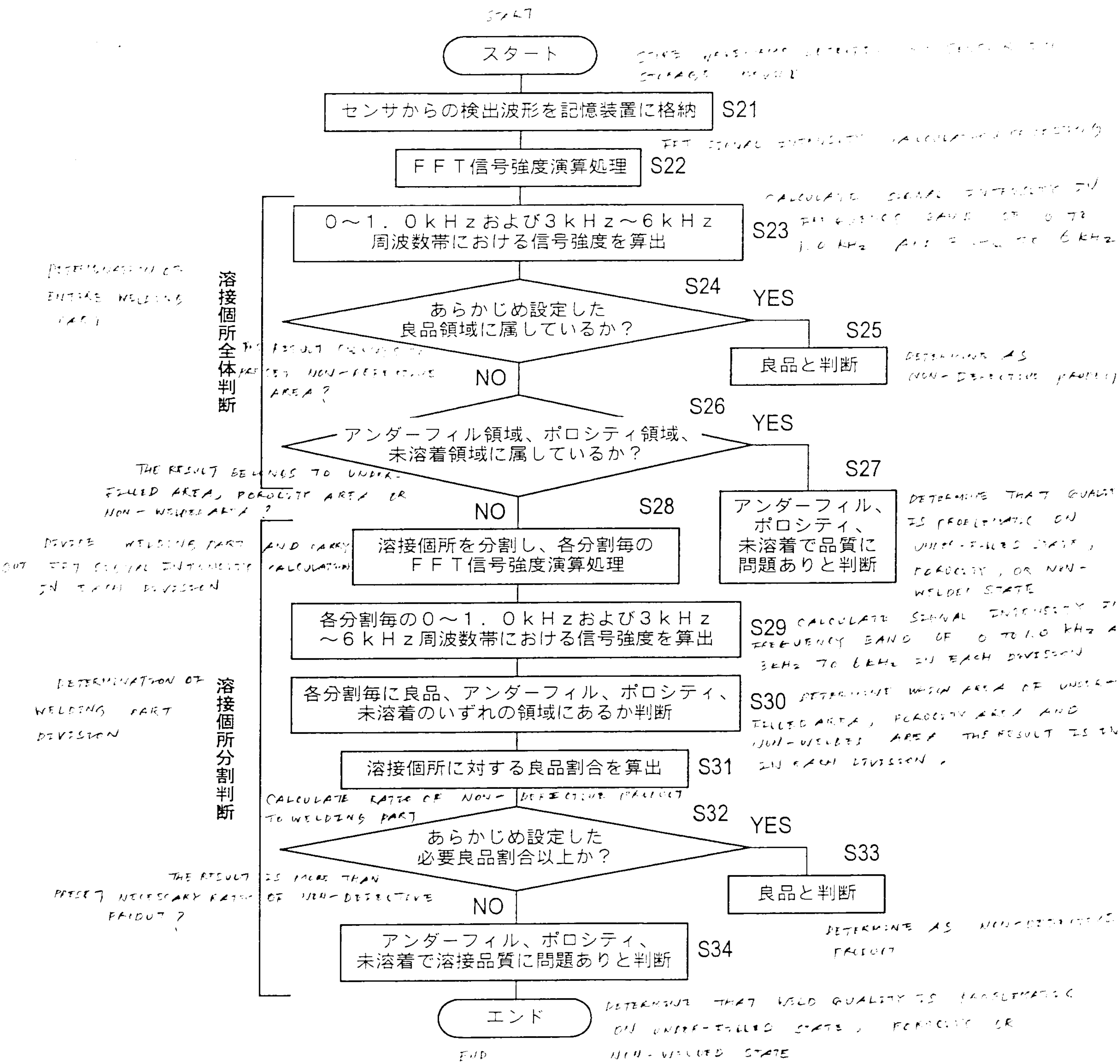
【図１６】
[Fig. 16]



【図１７】
[Fig. 17]



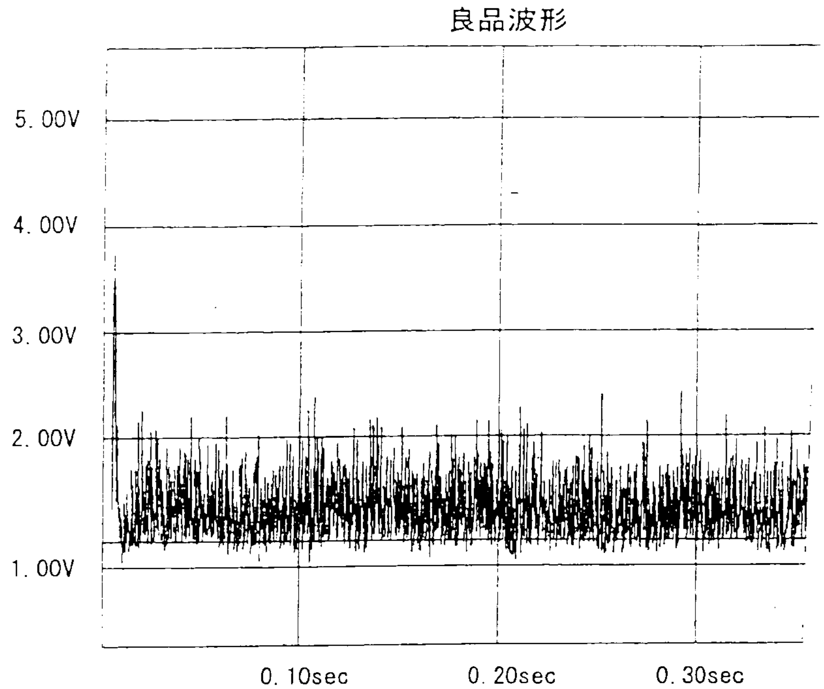
【図１８】


スタート
センサからの検出波形を記憶装置に格納
S21
ＦＦＴ信号強度演算処理
S22
０～１．０ｋＨｚおよび３ｋＨｚ～６ｋＨｚ周波数帯における信号強度を算出
S23
溶接個所全体判断
あらかじめ設定した良品領域に属しているか？
S24
YES
NO
良品と判断
S25
アンダーフィル領域、ポロシティ領域、未溶着領域に属しているか？
S26
YES
NO
アンダーフィル、ポロシティ、未溶着で品質に問題ありと判断
S27
溶接個所を分割し、各分割毎のＦＦＴ信号強度演算処理
S28
各分割毎の０～１．０ｋＨｚおよび３ｋＨｚ～６ｋＨｚ周波数帯における信号強度を算出
S29
各分割毎に良品、アンダーフィル、ポロシティ、未溶着のいずれの領域にあるか判断
S30
溶接個所分割判断
溶接個所に対する良品割合を算出
S31
あらかじめ設定した必要良品割合以上か？
S32
YES
NO
良品と判断
S33
アンダーフィル、ポロシティ、未溶着で溶接品質に問題ありと判断
S34
エンド
THE RESULT BELONGS TO UNDER-FILLED AREA, POROSITY AREA OR NON-WELDED AREA ?
CALCULATE RATIO OF NON-DEFECTIVE PRODUCT TO WELDING PART
DETERMINATION OF WELDING PART DIVISION
DETERMINE THAT WELD QUALITY IS PROBLEMATIC ON UNDER-FILLED STATE, POROSITY OR NON-WELDED STATE

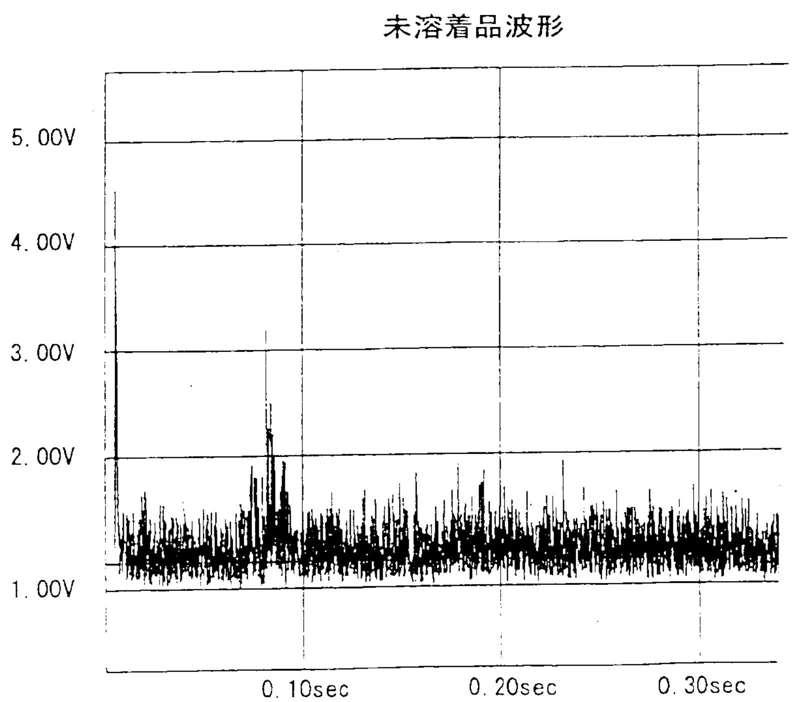
【図１９】

[Fig. 19]

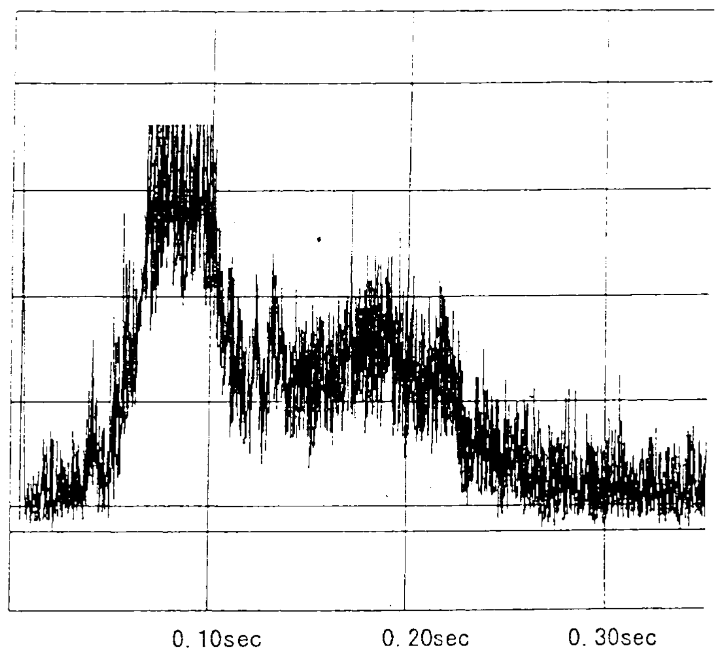
WAVEFORM OF WELD-ACCEPTABLE PRODUCT

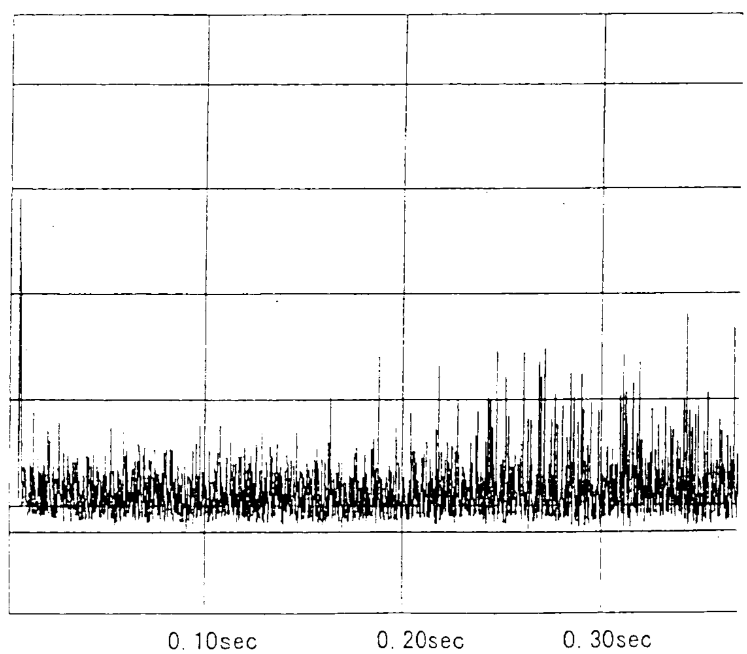


WAVEFORM OF NON-WELDED PRODUCT

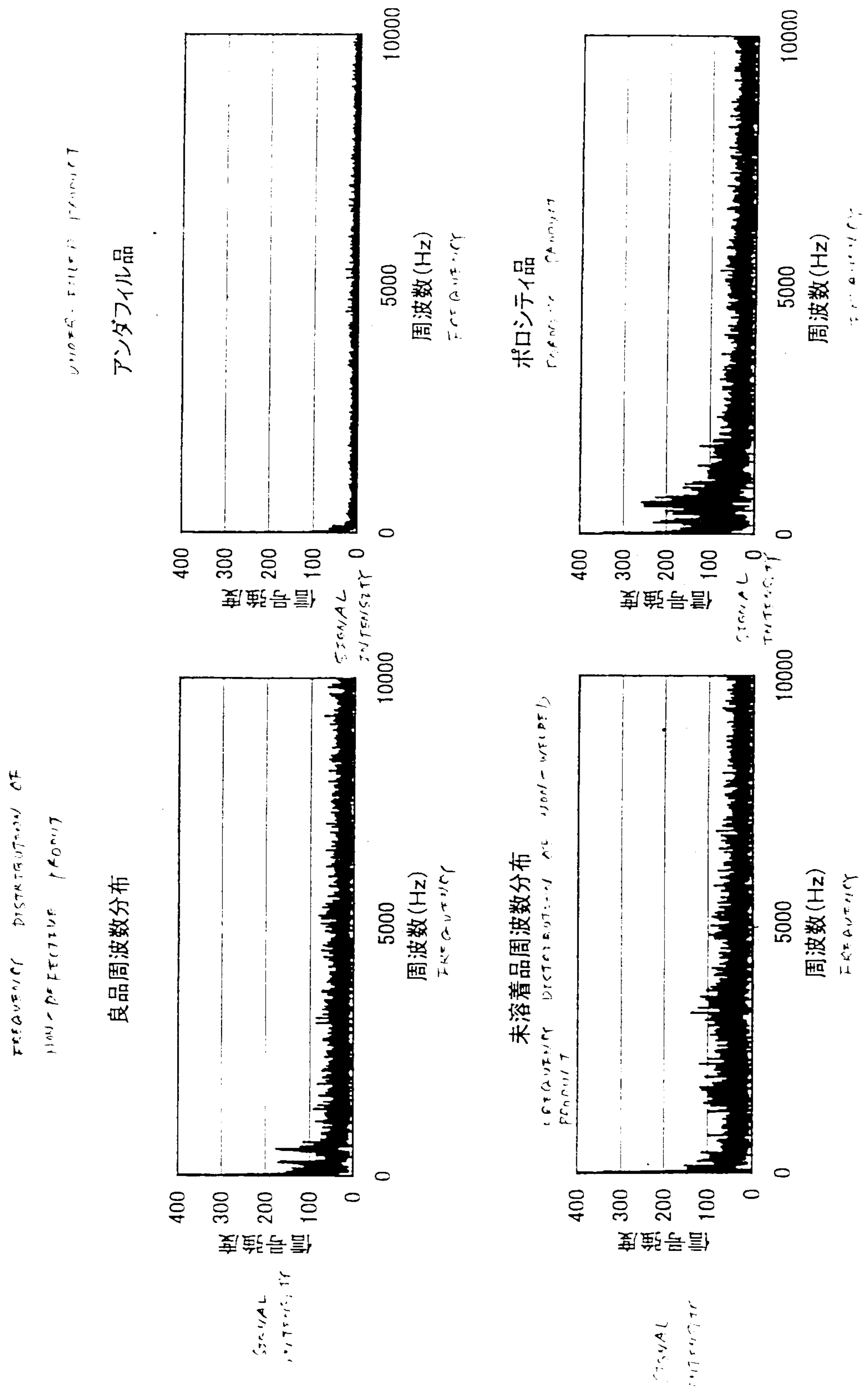


【図２０】


アンダフィル品波形
5.00V
4.00V
3.00V
2.00V
1.00V
0.10sec
0.20sec
0.30sec

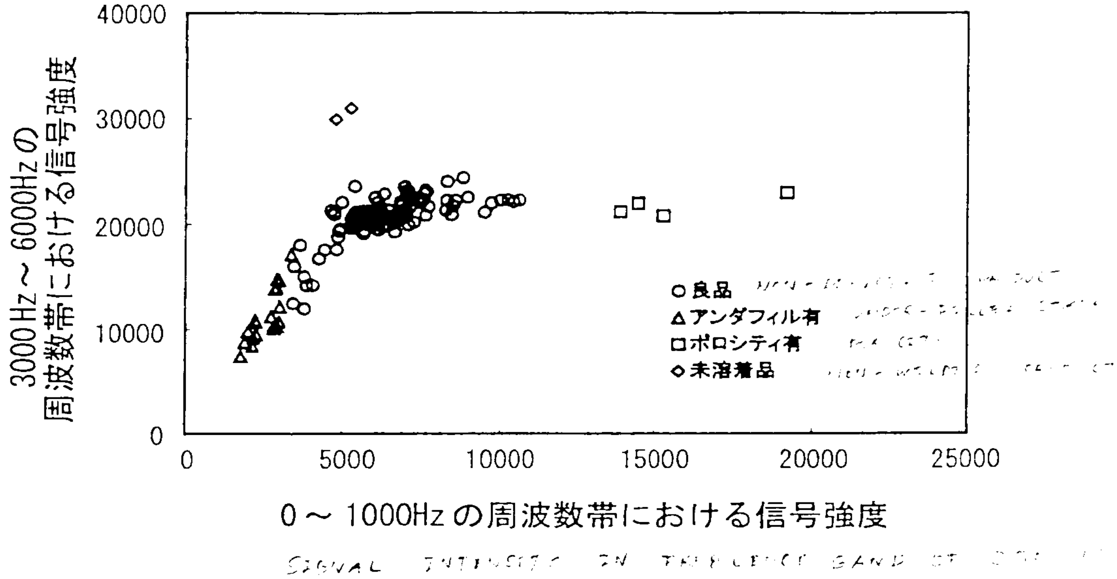

WAVEFORM OF POROCITY PRODUCT
ポロシティ品波形
5.00V
4.00V
3.00V
2.00V
1.00V
0.10sec
0.20sec
0.30sec

【図２１】
[Fig. 21]


良品周波数分布
アンダフィル品
未溶着品周波数分布
ポロシティ品
信号強度
周波数(Hz)
0
100
200
300
400
5000
10000

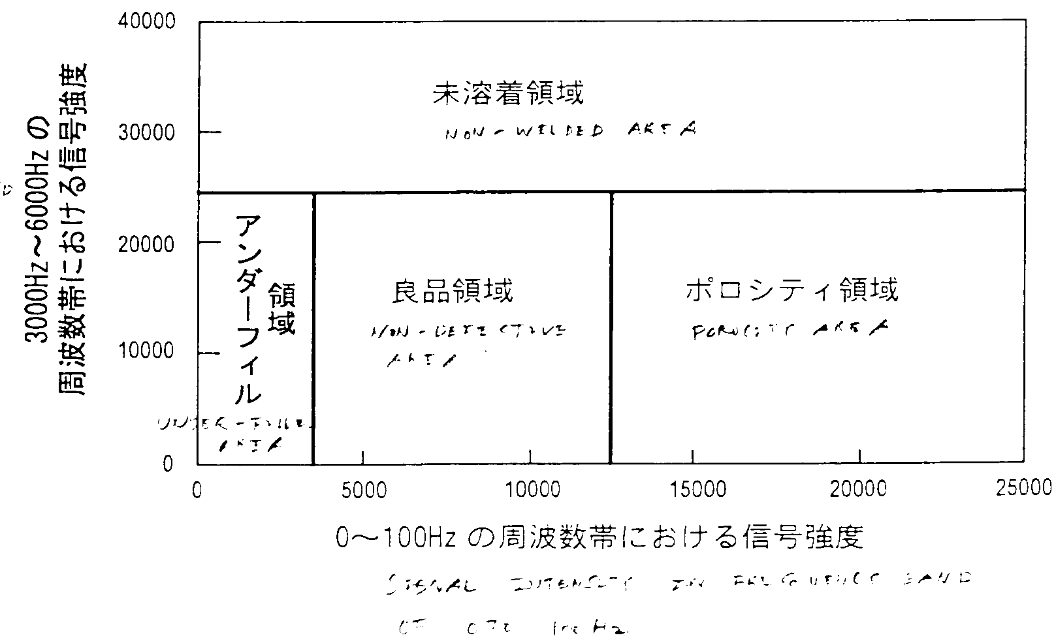
【図２２】

[Fig. 22]

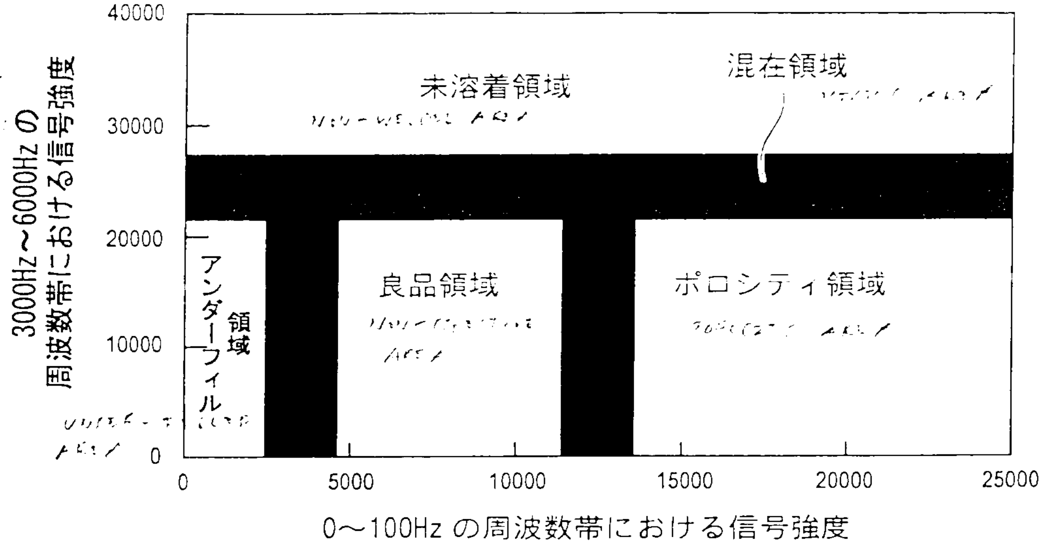


【図２３】

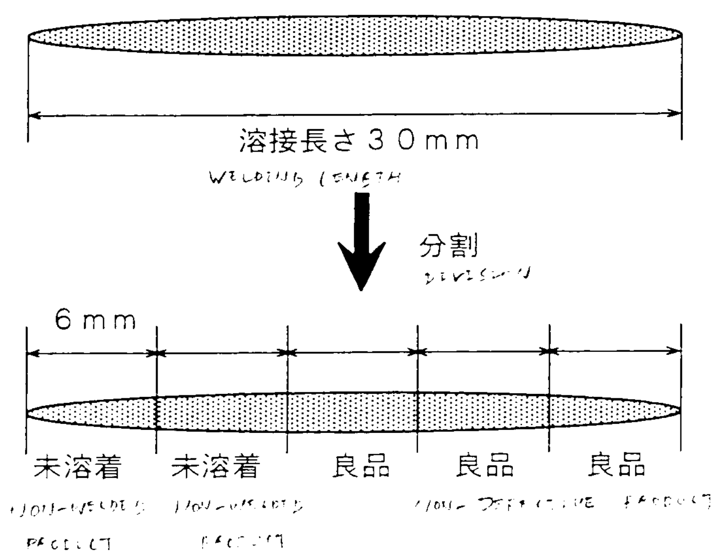
[Fig. 23]



【図２４】



【図２５】



良品割合＝ $\dfrac{\text{良品長さ６ｍｍ×３分割割合}}{\text{全溶接長さ３０ｍｍ}}$ ＝０．６